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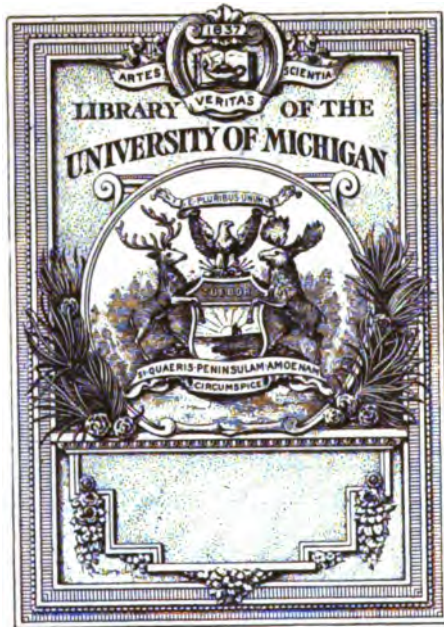
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MINUTES OF PROCEEDINGS
OF
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THE INSTITUTION
OF
CIVIL ENGINEERS;
WITH OTHER
SELECTED AND ABSTRACTED PAPERS.
VOL. CXIV.

EDITED BY
JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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THE SECRETARY,

THE INSTITUTION OF CIVIL ENGINEERS,

25, Great George Street, Westminster, S.W.

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C O R R I G E N D A.

Vol. cxiii. p. 279, last line, the right-hand member of the equation, for $\frac{x'' + (x'' + 1)}{2}$

$$\text{read } \frac{x \times (x + 1)}{2}.$$

„ p. 280, line 2, for $\frac{x''' + (x''' + 1)}{2}$, read $\frac{x \times (x + 1)}{2}$.

„ p. 281, line 6 from bottom, for “521,000,000,” read “521,000,000,000.”

„ p. 287, line 7 from bottom, add “per mile” after Rs.2,130 and Rs.6,300.

„ p. 297, line 5, for “cubic feet,” read “cubic yards.”

„ p. 303, last line of Table, for “10·27; 12·87; 8·22,” read “1,027; 1,287; 822.”

Vol. cxiv. p. 152, line 2, omit word “brought.”

„ „ line 3, for “of a,” read “description in the.”

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1892-93.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

11 April, 1893.

HARRISON HAYTER, President,
in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Members.

HUBERT CONGREVE.
GEORGE HENRY CROWTHER.
EDWARD BALDWIN JOHN KNOX.
HENRY DAVID ALEXANDER REID.

JOHN SAMPSON.
ERNEST SAMUELSON.
CHARLES HENRY SHORTT.

And that the following Candidates had been admitted as

Students.

ROBERT ALEXANDER JOHN BERRY.
ALFRED SAUNDERS CHAPMAN.
FRANKLIN CLARK.
PHILIP HENRY DAWE.
HERBERT PHILLIPS FLETCHER.
HENRY KEITH FORBES.
LEOPOLD WILLIAM HEATH.

HAROLD THORNTHWAITTE HINCKS.
HAROLD SISSON JACQUES.
EDMUND WILLIAM JANSON, B.A.
FREDERICK ARTHUR LART.
EDWARD EWING MATHESON.
ERNEST FREDERIC CROSBIE TRENCH,
B.A.I.

The Candidates balloted for and duly elected were : as

Associate Members.

ALEXANDER ADAMS.
EDMUND BATTERSBY.
HENRY WHITE BOWDEN.
WILLIAM FREDERICK BURROW.
ALFRED JOHN CHAMPION.
JOHN CUSHNY.
GEORGE GRIFFIN EADY.
MAURICE GRAHAM.
JOHN HOLLIDAY, Stud. Inst. C.E.
HORACE ARTHUR MCINTOSH.

ERNEST METEOR MARTIN.
CECIL RICHARDSON.
HENRY RODOLPH DE SALIS.
ROBERT SCHLOESSER.
ERNEST TALBOT.
ROBERT WILLIAM THOMPSON.
JAMES DENIS TWINBERROW.
HARRY MORTON WAYNFORTH, Stud.
Inst. C.E.

An Associate.

JAMES CLIFTON ROBINSON.

[THE INST. C.E. VOL. CXIV.]

B

(Paper No. 2622.)

“Steam-Engine Trials.”

By PETER WILLIAM WILLANS, M. Inst. C.E.¹

PRELIMINARY.

ABOUT four years ago, the Author made a series of trials of one of his central-valve engines, working non-condensing, and it was his intention to have immediately proceeded with trials of a condensing engine of the same type. A fire at Thames-Ditton in the year following that in which the former were made, made it necessary, however, to postpone for the time further trials; and it was only about a year ago that he was able to devote his attention to those which form the subject of the present Paper.

The engine used was similar to that with which the previous trials were made. The following were the principal points of difference between the two:—

(1) The proportions of the cylinders were altered to suit the changed conditions introduced by the use of a condenser. (2) The plan of transferring the steam to the other side of the piston, previous to exhausting it, was used in the low-pressure cylinder as well as in the high-pressure and high-high-pressure cylinders.² (3) A small clearance enclosed in the trunk between the central-valve and the cut-off ports was done away with, mainly for the purpose of simplifying the calculations of the steam shown by the indicator; although the change may tend to a minute extent towards increased economy.

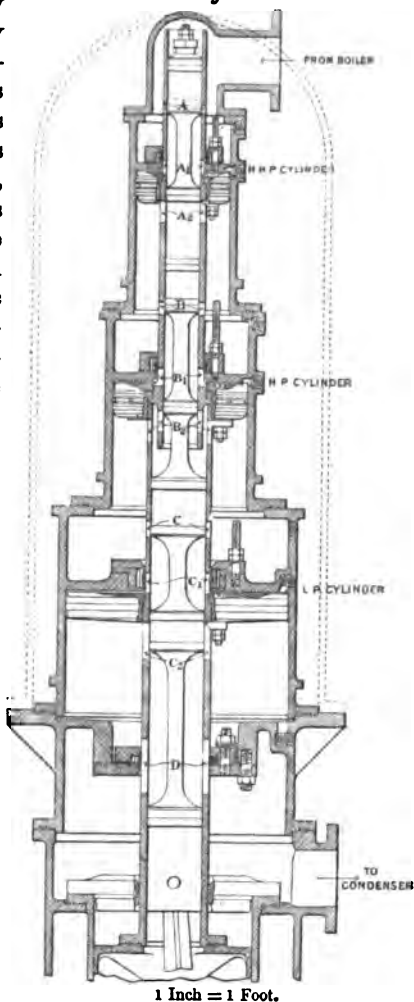
As the diameter of the low-pressure cylinder was the same in

¹ Owing to the unfortunate death of Mr. Willans before the Paper was in type, it has been revised, at the request of the Council, by his colleagues, Mr. Mark Robinson and Captain H. B. Sankey, R.E., who are also responsible for the footnotes throughout the Paper.

² This nomenclature was used by the Author in respect of the cylinders of his engines, viz., low-pressure (l.p.), high-pressure (h.p.), and high-high-pressure (h.h.p.).

the present as in the former trials, they may be compared without any allowances—such a comparison showing quite fairly the gain derived from the use of a condenser in one of two engines of the same type. As the engine has been frequently described, it is only necessary to allude to it briefly here. *Fig. 1* shows the general arrangement of cylinders and valves. The steam enters the first cylinder of the series by means of the ports $A A_1$, when the central-valve, as it moves upwards, opens the port A . When the port A passes through the metallic rings at the end of the cylinder, the steam is cut off; subsequently the central-valve closes the port A , and places the port A_1 in communication with the receiver beneath the piston by the port A_2 ; on the return stroke, the steam is transferred from the cylinder to the receiver. Thence, the steam enters and leaves the second and third cylinders of the series in a precisely similar manner, by way of the ports B, B_1 and B_2 , and C, C_1 and C_2 . On leaving the low-pressure cylinder, the steam is transferred in the same way to the under-side of the piston on the up-stroke, and on the next down-stroke it is allowed to escape into the condenser by the port D . In this way, the low-pressure cylinder proper, *i.e.*, the space above the low-pressure piston, is never in communication with the condenser. Any piston of the series can be removed, and the engine can be used as a simple-, a compound-, or a triple-engine at will.

Fig. 1.



The central-valve is actuated by an eccentric on the crank-pin. The particulars of the cylinders and the clearances are as follows :—

DIMENSIONS.

	Inches.
High high-pressure cylinder, diameter	6
High-pressure cylinder, diameter	8·5
Low-pressure cylinder „	14
Stroke	6

AREAS.

	Square Inches.
High-high-pressure cylinder area	22·86
" " " " under-side	21·78
High-pressure cylinder area	50·25
" " " under-side	44·17
Low-pressure „ area.	141·33
" " " under-side	139·72

CLEARANCES.

High-high-pressure cylinder, about 18 cubic inches (varies slightly with the cut-off).
High-pressure cylinder, about 23·5 cubic inches (varies slightly with the cut-off).
Low-pressure cylinder, about 65 cubic inches (varies slightly with the cut-off).
Stroke 6 inches.

Since the former trials were made, the testing-plant at the works has been completely reconstructed, with a view to testing with accuracy and rapidity a greater number of engines. In every-day engine-testing, when several engines have to be under steam together, and where sometimes only a few hours can be allowed for the trial of any particular engine, it has been found practically impossible to ensure that the whole of the steam-pipe connections shall be perfectly tight. Unless a considerable time can be devoted to preparing for and making an engine-trial, it is evidently impossible to trust to measurements of feed-water; as any leakages in the steam-pipes, safety-valves, and boiler-connections must be set right before the test begins. Further, the test must be of sufficient duration to practically eliminate the error due to the height of the water in the gauge-glass at the beginning and end of the run. The Author came to the conclusion, after full consideration, that, in the case of a closed engine in which the exhaust-steam chamber was completely isolated from the crank-chamber, the loss by leakage of steam from the engine could hardly be an appreciable quantity. If his conclusion is correct, it is evident that a method of weighing the condensed steam as it issues from the engine, offers great advantages in point of

accuracy, when considering such questions as the difference of the amount of initial condensation under different conditions.

The error due to the fact that the height of the water in the gauge-glass is not a true measure of the quantity of water in the boiler, is probably one of the most serious of those connected with an engine-trial based upon the system of measuring the feed-water. The height of water in the gauge-glass is affected by many circumstances, such as the state of the fires, the position of the feed-water pipe, and the rate at which the feed-water is supplied—and a trifling error may, if the boiler is large, mean a great difference in the results. The error from this cause can no doubt be practically eliminated by prolonging the trials; but it would be impossible to find time for such a series of tests as this Paper describes, if they were all extended so as to avoid any chance of inaccuracy from the causes named. A method of measuring the exhaust-steam was therefore designed by the Author, and, in making the ordinary commercial engine-tests, it was found that the figures did not appreciably differ from those obtained in the former trials, by measuring the feed-water pumped into the boiler, when scrupulous care was exercised to keep the boiler and the steam-pipes tight. In the case of the condensing trials, it was therefore decided to obtain the figures for water consumption by weighing the water discharged from the condenser; and in addition to make a sufficient number of protracted trials by the method of weighing the feed-water, to ascertain what correction should be made in those figures in order to cover the minute leakages that are inevitable in practice.¹ It will be seen hereafter that the leaks affecting the engine-consumption thus ascertained did not exceed 0.6 lb. per hour when the engine was consuming 330 lbs. per hour, the boiler pressure being 136 lbs. per square inch. The correction is therefore negligible. Having decided to weigh the discharge-water, it became possible to obtain readings, not merely for the whole run, but for short periods also, with great accuracy, so that if any change occurred in the conditions during the course of a trial it would not be overlooked.

Most of the trials detailed in the Tables that accompany the Paper were made with steam taken from a boiler doing other work, and the question arose as to the dryness of the steam from a range of pipes of considerable length. A separator was fitted as close

¹ Another boiler was used for these feed-measurement trials so as not to interfere with the ordinary testing-work, and it was moreover specially arranged for the easy detection of leaks.

to the engine as possible, and any water that collected in it was drained away. The steam from the upper part of the separator has been tested in the same calorimeter as was used 4 years ago, and when the boiler from which the steam was supplied had no very great load upon it, the steam was found to be dry—that is to say, its total heat agreed with the values obtained by Regnault. At other times, when a heavy load was on the boiler, a small percentage of water is believed to have been present in the steam after it passed the separator; but it is unlikely that it in any case exceeded $1\frac{1}{2}$ per cent. The special questions upon which the trials were expected to throw light are not very different from those which were enumerated in the Author's previous Paper;¹ but, as they are amplified in some respects, and slightly altered in others, it may be well to state here the objects of the present trials:

(1) To ascertain, under various conditions, the percentage of steam used in the cylinder to which the steam is first admitted, which can be accounted for by the indicator; to follow the course of the steam through the several cylinders in compound and triple-expansion engines, and to note its behaviour at later stages in the expansion.

(2) To observe the effect of speed of rotation, area of exposed surface, steam-pressure, and range of temperature, upon initial condensation, and upon economy generally.

(3) To fix, for condensing engines of this type, the best practical ratio of expansion with any given steam-pressure.

(4) To ascertain, with a given steam-pressure and ratio of expansion, the percentage of the theoretical mean pressure, which is in this type of engine actually obtained in practice.—PLANT EFFICIENCY.

(5) To ascertain the ratio of the work done by each pound of steam to the work due from it, under the limiting thermal conditions of each trial.—THERMAL EFFICIENCY.

(6) To determine for condensing engines, the steam-pressures beyond which it is desirable to use a compound or triple-expansion engine.

(7) To ascertain the consumption of steam at all loads, and under various conditions, in order to determine the most economical method, in different cases, of reducing the power of the engine.

(8) To arrive at some conclusion as to the circumstances under which jacketing is likely to prove advantageous before proceeding to the jacketed trials.

The main points of difference between the objects in view in these trials, and those in the previous non-condensing trials, have

¹ Minutes of Proceedings Inst. C.E., vol. xciii. p. 129.

been the more careful observation of the percentage of working steam present at later stages of the expansion in each cylinder, and the more complete investigation of the steam-consumption at lower loads. In the course of the last few years, the steady growth of electric lighting has brought prominently forward the question of the consumption of steam-engines at light loads. This is a subject which has been very little studied until recently. Engine trials have usually been made under the best conditions, or what were believed to be the best conditions, and very little therefore is known, for most types of engine, of the consumption at light loads. In these trials the engine was not jacketed,¹ and care has been taken that the steam should not be appreciably superheated by wire-drawing, except when it was expressly desired to study the effect of wire-drawing on economy. It is intended that the effect of superheating and jacketing shall form the subject of a later investigation.

It will be convenient to divide the Paper into 6 sections:

- A. The work theoretically due from a given weight of steam under various conditions.
- B. The method of making the trials.
- C. Descriptions of the Tables and of the main groups of trials.
- D. Description of a series of speed-trials.
- E. The losses localized on the $\theta \phi$ diagram.
- F. The economical value of automatic expansion-gear as a means of reducing the power.

SECTION A.

THE WORK THEORETICALLY DUE UNDER VARIOUS CONDITIONS FROM A POUND OF SATURATED STEAM WHEN EXHAUSTING INTO A CONDENSER.

It is desirable, as in the case of the non-condensing trials, to fix a back-pressure which may be used as a standard in order to determine the work theoretically obtainable from steam under various conditions. For this purpose the Author takes the pressure corresponding with a temperature of 110° F.,² namely 1.267 lb.

¹ In the usual sense. Nevertheless, the top of the cylinder (i.e., the working end, for the engine is single acting) is jacketed by the steam-chest in the case of the first cylinder, and by the receivers in the case of the later cylinders.

² Throughout the Paper temperature is denoted by T. Where definite temperatures are specified, the ordinary thermometer-reading is stated; the absolute numerical value of T being 491° Fahrenheit in excess of this amount.

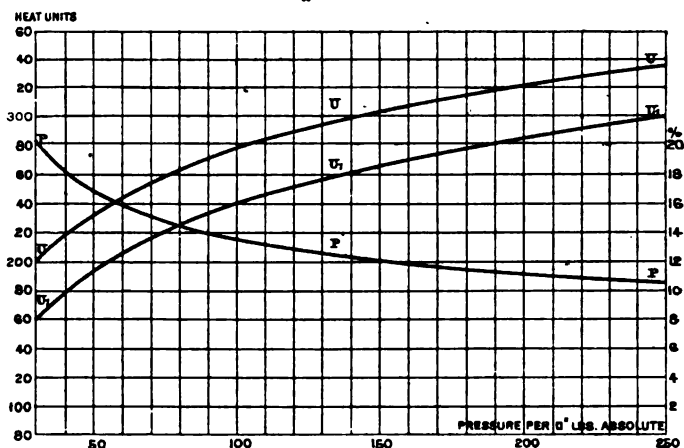
per square inch, or 2.576 inches of mercury.¹ Taking T_1 as the steam-chest absolute temperature, and T_0 as the condenser absolute temperature in degrees Fahrenheit, it is well known that the work in heat-units U due from a pound of saturated steam, on the assumption that the specific heat of water is unity, and that the latent heat of steam is $1438 - 0.7 T_1$, is

$$\left(1438 - 0.7 T_1\right) \left(\frac{T_1 - T_0}{T_1}\right) + T_1 - T_0 - T_0 \log_e \frac{T_1}{T_0}.$$

On *Fig. 2* the vertical ordinates from the curve U to the base,

Fig. 2.

VALUES OF U , U_1 AND $P - \frac{u - u_1}{u}$ FOR STEAM OF VARIOUS PRESSURES.



give the values of U for steam pressures, from 30 lbs. to 250 lbs. pressure. This value of U is taken as the highest ideal which the maker of a steam-engine can place before himself; it is the quantity which is geometrically represented on Mr. Macfarlane Gray's $\theta \phi$ diagram, *Fig. 3*, by the areas $K + L$. A description of this diagram, so far as it is necessary for ordinary steam-engine calculations, will be found in the Minutes of Proceedings of the Inst. C.E., vol. xcvi. p. 240, and it has been fully described by Mr. Gray in a Paper read before the Institution of Mechanical Engineers in Paris, in 1889.²

In *Fig. 3*, the areas $K + L$ give in heat-units the area of an

¹ On the ground that a lower vacuum can only be obtained at a cost exceeding the gain.

² Proceedings Inst. Mech. Engineers, 1889 p. 399 *et seq.*

indicator diagram (*Fig. 4*) due from 1 lb. of saturated steam admitted to a non-conducting cylinder, expanded adiabatically to the temperature of the back-pressure into which the engine exhausts, and discharged at that temperature. This standard is identical with that used for calculating the efficiency in the case of the Author's non-condensing trials, T_0 only being altered to suit the change in the back-pressure.

In the non-condensing trials, the thermal efficiency as before defined was in most cases about 80 per cent., that is to say, the work obtained from each pound of steam corresponded with about 80 per cent. of the whole area of the diagram shown in *Fig. 4*. It will be well to consider what change in the percentage of available energy realized by an ordinary steam-engine, is likely to be caused by discharging the steam into a condenser, *i.e.*, by adding to the range of temperature at the lower end of the scale. Whereas it is evident that the steam must be expanded down to the back-pressure in order to obtain the full value of the range available, it is certain that it is not advantageous to expand

Fig. 3.

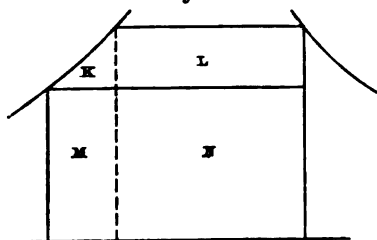


Fig. 4.



the steam to a pressure below what is necessary to drive the engine. Although, therefore, it is right to take a frictionless engine as the ideal, it may be well to realize at the outset the difference in efficiency which must necessarily arise from the practical limitation imposed upon expansion by the friction, to a greater or less extent inevitable in all engines. It is impossible to lay down rules to suit every case, but, for the sake of illustration, the Author will assume that it can hardly be worth while to expand in the cylinder below 170° F. in a condensing engine, or 226° F. in a non-condensing engine. The great difference between the practical and the ideal temperatures at the termination of the expansion in the two cases is remarkable. In the condensing engine this difference is 60° , whilst in the non-condensing engines it is only 14° . In other words, the shaded corner of the diagram, *Fig. 4*, lost by incomplete expansion, is necessarily a much larger

fraction of the whole diagram in the condensing than in the non-condensing engine.

It will therefore be well, while debiting each pound of steam with the full area of the diagram which physical laws show to be due from it, to calculate what this almost necessary loss amounts to in both cases, so that, in comparing the results of the condensing with those of the non-condensing trials, a correct opinion may be formed as to the relative performance of the engines.

The lower curve U_1 , *Fig. 2*, gives the heat-units due from a pound of steam after deducting the shaded corner in *Fig. 4*, and the curve PP gives the percentage of the total area U lost from this cause. The Table below shows these losses numerically, both for condensing and non-condensing engines. The formula for U_1 is

$$U_1 = (1438 - 0.7 T_1) \left(\frac{T_1 - T_2}{T_1} \right) + T_1 - T_2 - T_2 \log \frac{T_1}{T_2} + \frac{144 (p_2 - p_0) V_2}{772},$$

where T_1 is the initial temperature, T_2 that at the termination of expansion, and T_0 the temperature of the back-pressure respectively, and where p_2 and V_2 are the pressure and volume respectively at T_2 , V_2 being calculated for adiabatic expansion. This formula agrees with those of Rankine and Clausius if the specific heat of water is unity, and the steam is assumed to be dry.

		Condensing Engine— $T_2 = 170^\circ$, $T_0 = 110^\circ$.			Non-condensing Engine— $T_2 = 226^\circ$, $T_0 = 212^\circ$.		
Pressure, Absolute.	Tempera- ture, Fahrenheit = T_1 .	U.	U_1 .	Percentage of Loss.	U.	U_1 .	Percentage of Loss.
1	2	3	4	5	6	7	8
250.6	401	335.57	300.33	10.5	204.21	202.38	0.9
203.5	383	322.42	286.19	11.2	189.29	187.42	1.0
146.0	356	301.36	264.47	12.2	165.46	163.55	1.15
102.0	329	278.35	240.48	13.6	139.80	137.83	1.4
52.6	284	236.04	196.97	16.5	91.99	89.95	2.2
33.7	257	207.59	167.92	19.1	59.98	57.89	3.5

It will be seen that the deduction from the full area of the diagram is, in the case of the non-condensing engines, from 1 per cent. to over 3 per cent., while in the condensing engines it

amounts to from 10 per cent. to 20 per cent.; and, in comparing the percentage of available energy obtained from the engine in the non-condensing trials with that obtained in these trials, these necessary losses should be borne in mind.

Taking the heat-unit at 772 foot-lbs., the weight of steam required per HP. per hour is $\frac{2565}{U}$, if the steam is expanded to 110° F., the temperature of the assumed back-pressure; but if the shaded corner of the diagram be cut off at the temperature 170° F., the weight of steam required has the greater value $\frac{2565}{U_1}$. For calculating the thermal efficiency in line 35 of the Tables, the full value U has been taken as the standard, and therefore an engine designed equally well for condensing must give a lower percentage of the available energy than a non-condensing engine.¹

The method adopted by the Author in the case of the non-condensing trials, of fixing the theoretical limit to the number of expansions, was to assume that the relation of pressure and volume during expansion was expressed by the equation

$$p^6 v^7 = \text{constant.}$$

This equation is only approximate, and the error which it would introduce in condensing trials, owing to the increased range of temperature involved, could not be neglected. The number of expansions necessary to reach the limit fixed by back-pressure and friction, has, therefore, in these trials, been strictly calculated for adiabatic expansion, at several temperatures; the results are plotted on *Fig. 5* for pressures between 30 lbs. and 250 lbs. absolute.

The theoretical limit to the number of expansions N , with any given initial temperature T_1 , on the assumption that it is not expedient to expand below a temperature T_2 , is given by the formula

$$N = \frac{V_2}{V_1} \times \frac{\left(\log. \frac{T_1}{T_2} + \frac{L_1}{T_1} \right)}{\frac{L_2}{T_2}},$$

where T_1 is the absolute temperature of steam available;

¹ In the Paper on non-condensing engines, the heat-unit was taken by Mr. Willans as the equivalent of 770 foot-pounds. The thermal efficiencies given in the two Papers can, nevertheless, be compared without correction; because, as explained by Mr. Willans in the discussion on his earlier Paper, the slight error in the efficiencies occasioned by taking the figure 770 instead of 772 was neutralised by another slight error in an approximate formula used for ascertaining the work theoretically due from steam.

T_2 is the absolute temperature of the steam at the termination of expansion (fixed by condenser back-pressure and friction— 170° F. in the case under consideration);

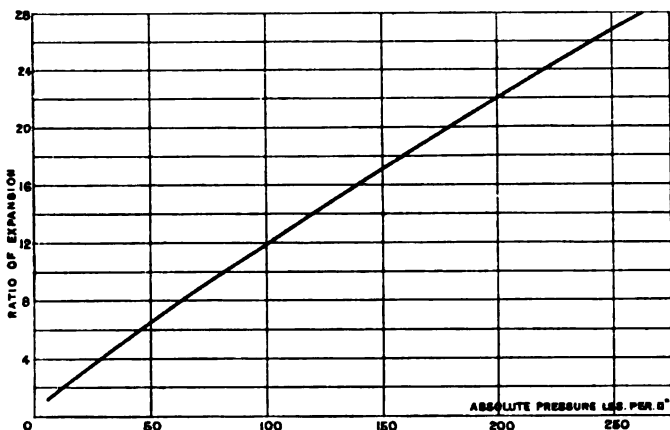
V_2 is the volume in cubic feet of 1 lb. of steam at T_2 ;

V_1 is the volume in cubic feet of 1 lb. of steam at T_1 ;

L_2 is the latent heat of 1 lb. of steam at T_2 (170° F.); and L_1 is the latent heat of 1 lb. of steam at T_1 .

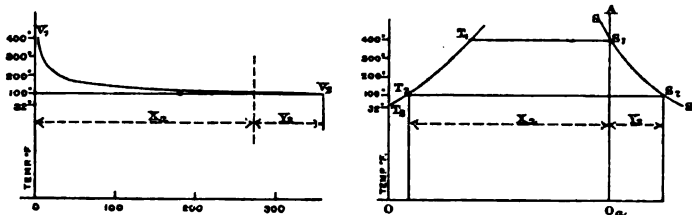
Fig. 5.

LIMITING RATIO OF EXPANSION, VARIOUS PRESSURES. FOR AN ENGINE EXPANDING TO 170° FAHR., AND EXHAUSTING AGAINST 110° FAHR.



Graphically, this comes out on the $\theta \phi$ diagram very simply, combined with a volume curve, Figs. 6; T_1 being the initial

Figs. 6.



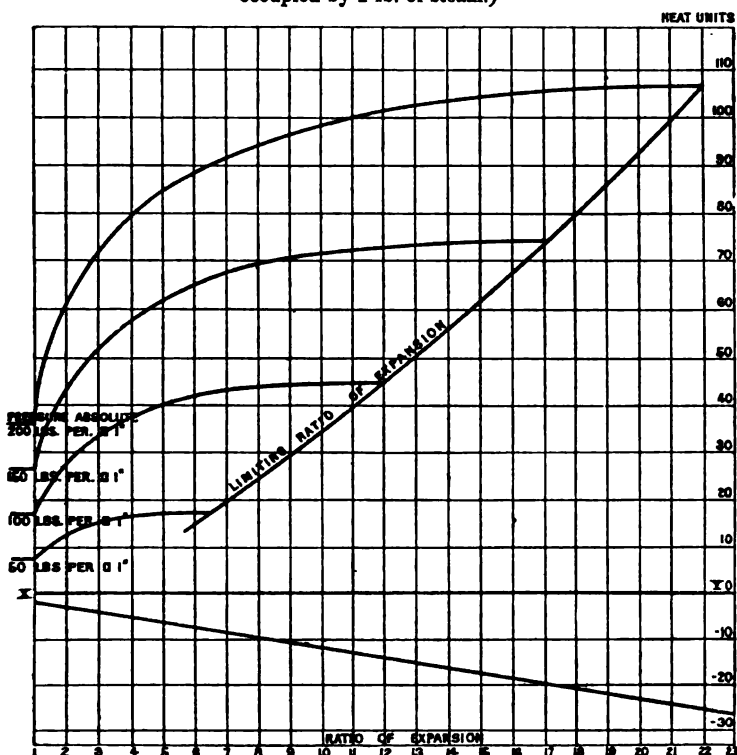
temperature, and T_2 the terminal temperature, fixed on account of back-pressure and friction. Through the point S_1 on the curve SS draw the perpendicular $A Oa$. Then, if the horizontal line $T_2 S_2$ be taken to denote the volume of 1 lb. of steam at temperature T_2 ,

x_2 to the left of the perpendicular $A O a$ denotes the fraction of the pound still in the state of steam after expanding from T_1 to T_2 , y_2 being the portion condensed up to that point and then present as water. In the volume curve to the left, the abscissæ from the curve $V V$ to the vertical $O O$ give the cubic feet occupied by 1 lb.

Fig. 7.

WORK THEORETICALLY DUE FROM 1 CUBIC FOOT OF STEAM AT VARIOUS PRESSURES.
EXHAUSTING AGAINST 110° FAHR.

(To obtain values per lb. of steam at same pressure, multiply by cubic feet occupied by 1 lb. of steam.)



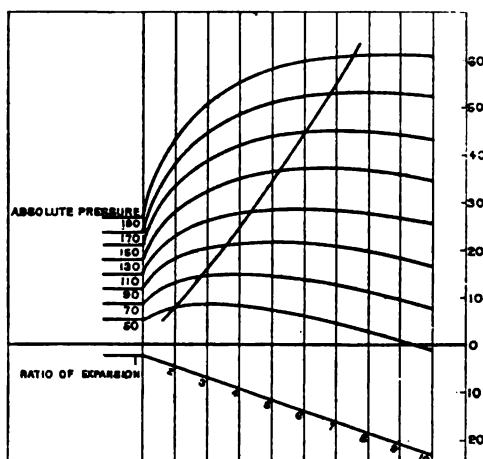
of steam at each temperature, the ordinates giving the temperature to the same scale as on the $\theta \phi$ diagram. If the abscissa $O V_2$ at temperature T_2 be divided in the proportion x_2 to y_2 , the fraction x_2 of the saturation volume V_2 will represent the fraction of the volume of the pound of steam remaining as vapour at T_2 , the ter-

mination of the expansion; while V_1 represents the volume at the commencement, and $\frac{x_2}{V_1} V_2$ gives the number of expansions necessary to reach T_2 .

The expansions given in *Fig. 5* have been calculated in this way, and it will be seen that, with the value of back-pressure and friction named above—i.e., with T_2 taken as 170° F.—the limit to the number of expansions for steam of 150 lbs. pressure (absolute) is about 17. On *Fig. 7* is shown, for steam of 50 lbs., 100 lbs., 150 lbs., and 200 lbs. absolute pressure per square inch, both this limiting ratio of expansion, and the work due with different ratios of expansion, from zero to the

Fig. 2, Plate 3, Minutes of Proceedings Inst. C.E., vol. xciii. (reproduced).

WORK THEORETICALLY DUE FROM 1 CUBIC FOOT OF STEAM AT VARIOUS PRESSURES EXHAUSTING INTO ATMOSPHERE.



limiting ratio in each case. The vertical ordinates measured from the diagonal base to the curves at each ratio of expansion give in heat-units, for each steam-pressure, the total work theoretically obtainable from 1 cubic foot of steam. The ordinates, measured to the curve from the line *XY*, give the useful work obtainable after deducting the losses assumed for back-pressure and friction, equal to about 6 lbs. per square inch on the area of the low-pressure piston. The curves are drawn on the assumption that the steam is used in the most perfect manner possible; and, instead of an approximate equation to the expan-

sion curve, as in the non-condensing trials, the adiabatic curve is employed. It will be seen that the position of the best point of cut-off is much more open to doubt in the condensing trials than in the non-condensing ones—(compare *Fig. 7* with *Fig. 2*, Plate 3, in the Paper relating to the non-condensing trials¹), a very large deduction from the length of the cylinder making little difference in the work theoretically obtainable. Here the commercial aspect of the question appears, for it is obvious that the cylinder should not be doubled in capacity without a very distinct gain in steam-consumption. It will be seen that, in the case of the curve for 150 lbs. pressure, the last third of the length of the cylinder gives only a gain of some 3 per cent. Each engine-builder must, of course, judge for himself, and for his own type of engine, the best ratio of expansion, but it seems clear that the highest ratio in *Fig. 7* is the outside limit which can be usefully employed.

Returning for a moment to the range of temperature between T_2 , the temperature at the termination of the expansion, and T_0 , the temperature of the back-pressure—which difference (in condensing engines) may be as much as 60° F.—it will be seen that this range, in the case of an engine using steam of 150 lbs. absolute pressure, or say 358° F., amounts to nearly one-quarter of the entire range of temperature—358° to 110°. The effect of this range, added to that due to expansion in the cylinders, may be very serious in its effect on economy.

The Author found that in the trials of his non-condensing engine quoted on page 256 of the Minutes of Proceedings Inst. C.E., vol. xcvi., the missing steam, present as water in the low-pressure cylinder, was 20·14 per cent. at the point of cut-off, and 15·26 per cent. at release—a mean of 17·7 per cent. absent during the expansive part of the stroke. When the engine otherwise in the same state exhausted into a vacuum of about 10 lbs., the missing steam was increased to 34·35 per cent. and 30·35 per cent. respectively—a mean of 32·35 per cent. throughout the expansion. Thus the steam present in the low-pressure cylinder in the condensing trial, was about 18 per cent. less than in the non-condensing one, the expansion being the same in both cases.

It appeared on this account worth while to adopt the transfer plan originally used on Cornish engines, and adopted by the Author in the high-pressure cylinders of the central-valve engine. This plan was described by him in 1884 (Patent Specification, 13,769,

¹ Minutes of Proceedings Inst. C.E., vol. xciii.

17th Oct., 1884), but, in the non-condensing engine, the small range introduced by the 5-lb. toe of the diagram, only 16° F. was not sufficient to warrant its adoption. In the case of the condensing engine it is, however, different. Not everyone realizes that the secret of the economy of the old Cornish engine was mainly that, by adopting this plan, the temperature-range, so far as it affected the pistons and cylinder ends, was practically halved; and that on this account the Cornish engine held its own economically against the compound engines of the day, until the employment of increased pressures necessitated more complete separation of the temperature stages.

SECTION B.

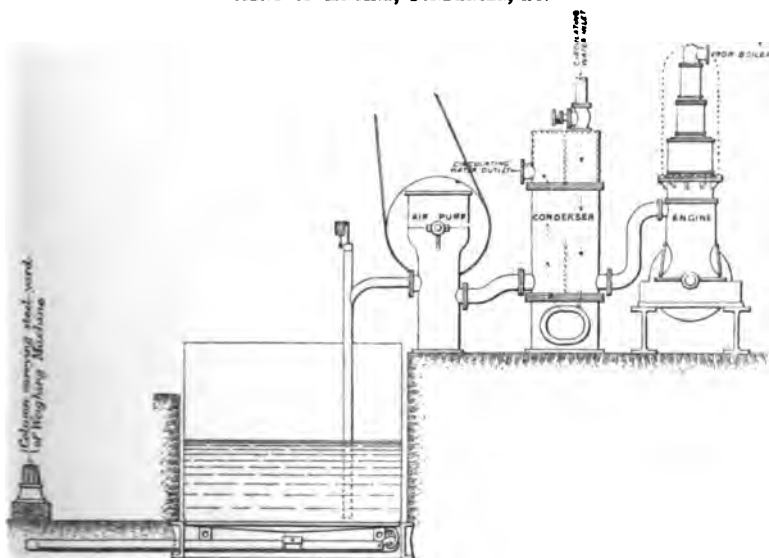
THE METHOD OF MAKING THE TRIALS.

As the main point in these trials was the determination of the quantity of steam used under varying conditions, great care was taken to avoid errors in its measurement. The steam passing away from the engine was led into a surface-condenser (*Fig. 8*). From the condenser it was drawn by an air-pump fitted with a cover over the hot well, but otherwise of ordinary construction. From the hot well the discharged water was conveyed into a tank, mounted on a 3-ton weighing-machine. In order to avoid any chance of vapour passing from the condensed steam, the pipe conveying the discharge-water from the hot well was taken nearly to the bottom of the tank by a vertical pipe. This vertical pipe was also continued upwards beyond the bend leading from the hot well, and at the top was placed a small coil, to intercept, condense, and deliver into the tank any vapour which might possibly rise. As a matter of fact, no steam was seen to escape during the whole course of the trials. It was important that the discharge-water should leave the condenser and enter the tank at as low a temperature as possible, in order to avoid any loss by evaporation. Accordingly, the bottom of the condenser was so arranged that a certain quantity of water always lay there, and the air-pump drew the water from this recess. The water, therefore, lay on the cool lower tube-plate, and the result was that its temperature was generally about 70°F. It will be understood that this arrangement was merely introduced in order to measure the steam used as accurately as possible; it would of course be unsuitable where it was desired to obtain a hot feed.

The arrangement of engine, condenser, air-pump, and tank are shown in outline in *Fig. 8*, but the connecting pipes were in fact somewhat longer than there indicated. Care was taken to have a fall for the water all the way from the engine to the air-pump, and from the air-pump to the tank, in order to avoid any irregularity in the discharge. To still further guard against evaporation from the surface of the tank, it was arranged that a film of oil should always lie on the surface of the water. Under these circumstances, it

Fig. 8.

TRIAL ENGINE, No. 661. 14 INCHES $\times$ 6 INCHES. DIAGRAM SHOWING ARRANGEMENT OF ENGINE, CONDENSER, &c.



would have been strange if there had been any considerable difference between the weight of the water entering the boiler and of that leaving the engine; but, as the question of the amount of this difference has frequently been raised in discussions upon engine-trials the Author decided to ascertain specially if any addition was necessary to cover leakage.

The trials made with this object are described hereafter, and show that the leakage did not exceed 0.21 per cent. This loss being insignificant, it was not allowed for in the main groups of trials, in which the water was only measured as it entered the tank. No doubt the loss varies with change of pressure, but

such a minute addition to the quantities in the Tables may be neglected practically. Thus the Author has been able, by weighing the discharge-water only, to obtain remarkably uniform results, without extending each test to more than 2 or 3 hours. As a matter of fact, the trials might have been, without sacrificing accuracy, of much shorter duration.

The engine was usually run for about an hour before the commencement of the trial proper. A counter was fitted, capable of recording the revolutions over the entire run, and of being placed in or out of gear rapidly. All being in order, and the water steadily flowing into the tank, the weight was adjusted on the scale-beam of the weighing-machine, so as to keep it down. When the beam lifted, it was arranged to ring an electric bell, and when this bell rang, the counter on the engine was put into gear, and the time noted. The weight on the scale-beam was then shifted forward 100 lbs. or 50 lbs., according to the rate at which steam was used; and when the bell again rang, the time and revolutions were again observed and noted, but without withdrawing the counter. Thus, not only was a reading taken for the whole run, but accurate readings were also taken for each 50 lbs. or 100 lbs. of steam used; the advantage of the check thus afforded on the accuracy of the trial is obvious. In Appendix I is given one of the sheets of particulars of revolutions, water-consumption, &c., taken during a trial; from which it may be seen that the interval of time in the "running time" column for each 100 lbs. of water used, does not differ from the mean by more than about 2 per cent. The indicator diagrams were taken by Crosby indicators, of which the springs had been checked hot. The diagrams have been measured by two assistants in every case. Usually the two measurements agreed throughout within about $\frac{1}{2}$ per cent., and the mean has been taken. Where larger differences appeared, the cards were re-measured. The diagrams from each cylinder for every trial have been measured collectively, a method which avoids many minute readings of the planimeter, which are necessary if each diagram is measured individually. In the same way, the measurement of the diagrams for steam present, are the means of the measurement at each point of every diagram taken. In the great labour involved in these trials, the Author was assisted by Messrs. W. E. Burgess, Stud. Inst. C.E., H. O. Beckh, M.A., Assoc. M. Inst. C.E., and A. Lazenby, B.A., Assoc. M. Inst. C.E., and he desires to record the care and interest which those gentlemen bestowed upon the work. Only those who have made an extended series of trials of this nature can have any idea of the extreme

care required to obtain consistent results; and, from the results as plotted on the straight-line diagrams for steam-consumption, some idea may be obtained of the accuracy with which these trials have been made and their results calculated.

The weighing machine was checked by standard weights several times in the course of the trials. The pressure gauges and thermometers have also been compared with standard instruments. The condenser has been from time to time tested for tightness, by placing its upper end in communication with the air-pumps, and fitting a water-gauge at its lower end in which any increase of water would be at once observed. It always proved to be tight. The pistons were tested from time to time, and the leakage was very slight indeed, in fact, hardly measurable. This, however, is no proof that they were tight when running. The engine was coupled to a dynamo delivering current through a resistance, the electrical instruments being close to the observer. There was thus no difficulty in keeping the load constant, or in varying it as desired.

SECTION C.

DESCRIPTION OF THE TABLES.¹

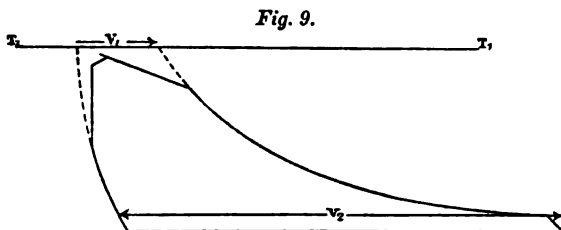
The letters at the head of each column of the Tables give the reference to the trial-records, and serve as a short name for each trial. The nomenclature adopted shows the conditions under which the trial was made. C $\frac{130}{4.82}$, for instance, signifies that the engine was working compound with an intended mean admission-pressure of 130 lbs. per square inch absolute, and an intended expansion ratio of 4.82. This ratio is found by dividing the volume swept by the low-pressure piston by that swept by the high-pressure piston up to the point of cut-off.

The temperatures T_1 and T_0 , used for calculating the thermal efficiencies given in line 135, are given in lines 6 and 10, except in cases where the steam is intentionally superheated, which will be referred to hereafter. These temperatures were chosen because they can be easily observed, and because they really limit the

¹ The particulars of these trials are given in detail in Table I, Appendix III. The voluminous nature of Tables I-IV, Appendix III, renders their retention in the Proceedings undesirable, especially as the results are represented diagrammatically in the Plates 1 and 2. The Tables may, however, be had on application.—Sec. INSR. C.E.

power for work contained in the steam when it reaches and leaves the engine. If a feed-water heater is used, the feed can, theoretically, at any rate, be heated to the temperature given in line 10; and if it is not used, there is no reason why the engine proper should be debited with a larger range of temperature than would be the case if a feed-water heater were employed. A comparison of lines 5 and 6 will show that the observed pressure and temperature in the steam-chest practically agree. In the exhaust-chamber the temperature only was taken, but the back-pressure (lines 7 and 7a) in the condenser, which was only a few feet away, is a fair check on its accuracy.

LINE 11. CORRECTED RATIO OF EXPANSION.—This has been determined by taking as V_2 , *Fig. 9*, the volume of steam at terminal



pressure discharged from the low-pressure cylinder, and as V_1 , such a volume of saturated steam at the steam-chest temperature, as would correspond with the steam shown by the indicator to be present at the point of cut-off. This method includes in V_1 any steam required to fill the clearance from the cushion-pressure, sometimes a plus and sometimes a minus quantity, but it does not take account of steam condensed before the point of cut-off.

LINE 17. RUNNING TIME.—The results of the trials have, for the sake of simplicity, been calculated on the assumption that the engine was running at a certain speed. A "running hour" means, therefore, the number of revolutions which the engine would have run in an hour, if its nominal speed had not varied. This method makes the comparison of the total water used, and of the missing quantities in each trial, quite simple—so far as they may be considered to be unaffected by small irregularities in the rate of revolution.¹ In considering the trials made at 100 revolutions

¹ It is obvious that it can make no difference whether the consumption of steam per indicated HP. per hour is deduced from the total amount used during 24,000 revolutions in 58 minutes, or 24,330 revolutions in 60 minutes, seeing that the HP. also varies with the revolutions. In this case 58 minutes constitutes the "running hour."

per minute and in some other cases, the results may require slight correction before they can be plotted on a revolution base; because, at that low speed, the difference between 100 revolutions and 115 revolutions per minute, at which most of them were made, is comparatively important in its effect upon cylinder-condensation. The actual mean revolutions per minute are also given in line 18, to facilitate any investigations of this kind.

LINES 27 AND 28.—In the non-condensing trials described in his former Paper, the object of the comparison of the mean pressure obtained in practice with the mean pressure theoretically due from steam expanded to the same extent, was not, the Author thinks, understood by everyone. This comparison has no reference to efficiency properly so called, but it is important commercially; for it indicates the ratio of the power obtained with a given steam-pressure and ratio of expansion, to that which should be obtained if the steam were expanded to the same extent in the most perfect manner possible. The Author calls this ratio the **PLANT EFFICIENCY** as distinguished from **THERMAL EFFICIENCY**. It sometimes happens that, without any material change of thermal efficiency, the plant-efficiency may be much increased by special treatment; and this is a point which should never be lost sight of, particularly as an increase in plant-efficiency is necessarily accompanied by an increase of useful power. The method of calculating the theoretical mean pressure is given in Appendix II. The adiabatic curve has been used instead of any arbitrary one for the calculation of the area of the ideal diagram.

LINE 29.—The indicated HP. is calculated on the assumption that the revolutions are 400, 300, 200, &c., per minute, and not on the slightly different mean revolutions given in line 18. The water per I.H.P., given in line 32, is therefore the water used for 24,000 revolutions, 18,000 revolutions, or 12,000 revolutions, etc., as the case may be.

LINES 34 AND 35. THERMAL EFFICIENCY.—The figures in these lines are calculated in the same manner as in the case of the non-condensing trials.¹ A full explanation of the reason for adopting the standard chosen, viz., the area of the diagram obtained from 1 lb. of steam expanded adiabatically from the higher to the lower temperature, and expelled at the lower temperature, was given in the Author's reply to the discussion upon his former Paper.²

¹ See footnote 1, p. 11.

² Minutes of Proceedings Inst. C.E., vol. xevi. p. 234.

LINES 54 TO 59 give the heat missing at cut-off, per running hour and per stroke, in heat-units. They are given for the cylinder which the steam first enters.

LINES 36 TO 53. STEAM PER HOUR ACCORDING TO THE INDICATOR.—The figures are also calculated on the running-hour basis. Those for the 400-revolution trials are therefore really the figures for 24,000 revolutions, as in the cases named above.

LINES 60 TO 77. TEMPERATURES DURING EXPANSION.—These are based on the pressures obtained from the diagram measurements. The figures in lines 78 to 84 are given to facilitate a comparison between the heat-units missing in the first cylinder of the series, and the conditions as to surface, range of temperature, and density of steam, which may be assumed to account for the loss.

LINE 83 gives the weight of water which, assuming it to be permanently present in the cylinder, and to be raised at each stroke through the range between exhaust-temperature and mean admission-temperature, would account for the abstraction of heat given under the heading, "Heat-Units missing at cut-off." It should be clearly understood that the figures given in line 83 are not supposed by the Author to be an accurate measure of a body of water in the cylinder. They are given as a convenient arithmetical equivalent of the combined weight of water and iron whose temperature is raised by the in-coming steam.

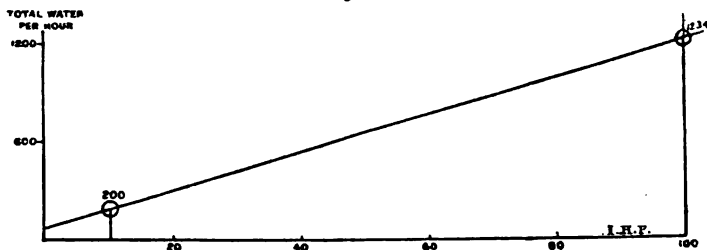
LINES 85 TO 102. CONDENSATION OR RE-EVAPORATION DURING COMPRESSION.—These are based on diagram measurements necessarily minute and difficult to obtain. The figures given in lines 90, 96, and 102, apply to the cushion-steam at the moment of admission; its volume is then accurately known, and its pressure is believed by the Author to be as easily determined as any other quantities measured by the indicator, and to be more certain than the figures given in lines 89, 95, and 101, which are based upon measurements made under greater difficulties, both in respect of pressure and volume.

DESCRIPTION OF THE MAIN GROUPS OF TRIALS.

Since the non-condensing trials were made, the Author, in the course of his ordinary engine-tests, found that when the power of an engine was reduced by lowering the boiler pressure—the revolutions being constant—the total quantity of water used per hour could be represented by a fixed multiple of the HP. plus a constant. For example, if an engine of 100 I.H.P. takes 1,234 lbs. of water per hour to run it at full load, and 200 lbs. at

one-tenth load, the total water at any intermediate load may be found by plotting the two quantities named above as ordinates to a base representing horse-power, and drawing a straight line through the two given points, thus:—

Fig. 10.



In the diagrams illustrating the present trials the base-measurements indicate power expressed as mean pressure per square inch of the low-pressure piston-area, *i.e.*, the pressure on all the pistons is included in these measurements by the application of suitable factors for difference of area. (At 400 revolutions per minute in this particular engine, the mean pressure must be multiplied by 0·856 in order to give I.H.P., and by a proportionate figure if the revolutions are varied.) The ordinates give the total quantity of water used per hour at each mean pressure.

An outline of this method of plotting was given by the Author in his remarks upon Mr. R. E. B. Crompton's Paper on "The Cost of the Generation and Distribution of Electrical Energy."¹ The present Paper deals with indicated HP. only, and the zero of power is therefore the same as the zero of mean pressure. When the power is altered by varying the steam-pressure, the two factors which determine the cost are—*w* the water which would be used by the engine at zero mean pressure, supposing it to be frictionless, and therefore able to run with an infinitely small mean pressure, and *K* the cost per hour of producing each pound of mean pressure in that particular engine. Denoting the mean pressure by the letter *P*, the indicated HP. will be denoted by *x P*. The total water per hour for the HP. corresponding to the mean pressure *P*, will be, according to the above law, *w* + *K P*, and the water per I.H.P. per hour will be

$$\frac{w + K P}{x P} = \frac{w}{x P} + \frac{K}{x}.$$

¹ Minutes of Proceedings Inst. C.E., vol. cvi.

In the diagrams for the main groups of trials now to be described, the changes in w and K at various ratios of expansion determine the relative economy of the engine under the different conditions.

The values of w and K are given on the diagrams for each group of trials. Also the value of $\frac{K}{x}$, strictly speaking the most important quantity, being the cost per I.H.P. after the expense of running the frictionless engine has been paid.

Figs. 11, 12, 13, Plate 1, give the results of the simple trials at about 400 revolutions per minute. The particulars of these trials are given in Table I, Appendix III. The upper line on each diagram gives the total quantity of water per hour. This line is drawn through the mean positions of the points showing the water-consumption actually observed. The lower lines are similarly drawn through the mean positions of the points denoting the steam shown by the indicator present at various stages in the expansion. The indicator-diagrams of these simple trials have been measured at 4 points, but for the sake of clearness only two of them have been plotted on the diagrams, viz., at cut-off and release. The quantity indicated by the height of any point in these lower lines is the steam present in the cylinder, according to the indicator diagrams, after deducting the play steam present at admission (Appendix IV). The points are lettered to correspond with the trials. The quantity of water required to give 50 lbs. per square inch mean pressure, with the ratio of expansion at which each group is made, is given in figures, as well as w the water required by a frictionless engine doing no work at the revolutions specified is also given;¹ the figures for any intermediate point may therefore be calculated accurately, if the small scale of the diagrams prevents accurate measurement.

Figs. 14 to 21, Plate 1, give in a similar manner the results of the compound trials. These trials were made with nominal ratios of expansion of about 4.8, 10, and 15.5. Two compound trials were made at 20 expansions, but as they did not show any practical difference from those made at 15 expansions, the series was not continued, and the trials made are not plotted on the diagrams. The compound groups of trials were made at various revolutions, and the effect of varying the speed will be more fully dealt with in the next section of the Paper.

¹ Steam would still be used to balance the losses from radiation, from initial condensation, and from conduction of heat through the metal from the hotter parts of the engine to those which are in contact with the exhaust.

Figs. 22, 23, and 24, Plate 1, give the results of a series of triple trials made at about 12 and 20 expansions; Figs. 22 and 24 at 400 revolutions, and Fig. 23 at 300 revolutions.

Following the upper line indicating the total water-consumption on each diagram, it is found that, as the power is increased, each equal increment of steam-pressure gives practically an equal increment of mean pressure, and, consequently, of horse-power. It is, therefore, possible to make the straight line indicating total water-consumption into a pressure-scale: this scale gives the average pressure (absolute) observed in the steam-chest of the engine. It will be seen that in the same way as the total water per hour at any mean pressure is the sum of two quantities, viz., $w + K P$, so the steam-pressure required in the steam-chest is the sum of two quantities, viz., p , the pressure required at the given ratio of expansion by a frictionless engine when doing no work, and $c P$ a fixed multiple of the mean pressure at any other power.

It might be thought that if the power were reduced, not by lowering the boiler-pressure, but by cutting off earlier and increasing the ratio of expansion, and therefore the steam-pressure throughout the entire range of power, the total water per hour ($w + K P$) would be reduced at all loads, and that w would, therefore, be reduced, but this is not usually the case.

When the expansion is increased, two changes usually occur in the straight-line diagram. w is in most cases increased, and K is reduced. The reason of this increase in w is obvious, if the point of zero LHP. or mean-pressure in an engine working without friction, at, say, 5 expansions, be considered. The diagram at zero power would be somewhat as shown by the full lines in Fig. 25, in which the line OO denotes the absolute zero of pressure, BP the line of back-pressure, and $P_1 P_2$ the highest and lowest pressures in the cylinder: the sum of the two areas, positive above the BP line, and negative below it, must, in a frictionless engine doing no work, be zero. Comparing with this the dotted diagram for increased expansion, in which the sum of the positive and negative areas must also be zero, it will be seen that P_1 and P_2 , the initial and final pressures, must necessarily be much further apart. From this it follows that the radiation, conduction, and cylinder condensation must be increased as the expansion increases; and at zero mean-pressure the gain due to increased expansion seems to be usually outweighed by these increased losses.

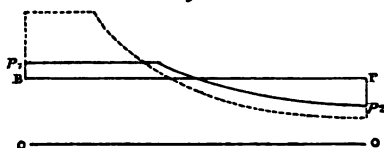
This matter is again referred to in Section F.

The Author thinks that the trials are fully explained by the

Tables and diagrams, but wishes to direct attention to the method of plotting the results. By its use, no accidentally high or low result is liable to be treated as of exceptional importance. The water-consumption line is the mean-line in each case for a progressive series of trials, and the extremely small divergence of the actual points from this mean-line, gives a guarantee of accuracy which probably could not be obtained in any other way.

It should be observed that, not only do the dots denoting total water-consumption lie in a straight line, but the dots denoting the quantities of steam shown by the indicator to be present at different points of the expansion, seem also to follow the straight-line law. Their divergence from the straight line is, however, greater, as might be expected from the fact that their positions are based upon the measurement of particular points in the diagrams; still, there is every reason to believe that the straight lines drawn through them are not far from the truth. In all the Figs., 11 to 24, in this section, the curve plotted downwards from left to right gives the water-consumption per I.H.P.

Fig. 25.



This curve is calculated from the total water-consumption given by the straight line, and not from the observed results, and is a rectangular hyperbola.¹

The Author had intended to embody in this Paper the results of trials made at much higher pressures than those given. Unfortunately he was disappointed in the delivery of the boiler which had been ordered for the purpose. He had also intended to make comparative trials of the water entering the boiler and leaving the condenser with this high-pressure boiler. As it was not ready, the check trials have been made with an ordinary multitubular boiler of the marine type, which has for some years been employed in generating steam for the factory engine. The comparison is perhaps more interesting as the boiler was not in any way a special one, nor specially prepared for the purpose. In order to test its steam-tightness, a trial of 29 hours' duration was made

¹ See Captain Sankey's remarks in the discussion on Mr. Crompton's Paper previously alluded to. Minutes of Proceedings Inst. C.E., vol. cvi.—P. W. W.

at a pressure of 100 lbs. per square inch. Several trifling leaks were noticed—that from the safety-valve being perhaps the worst. The water lost, as measured by the fall in the gauge-glass of the boiler during twenty-nine hours, was found to be 3 lbs. per hour. The boiler was then moved from its ordinary position into the test-room. A trial was made, of 8 hours' duration, of engine and boiler. In this trial the feed-pump drew from the weighing-tank, already described, and the air-pump discharged into it. If, therefore, the water stood at the same height in the gauge-glass at the beginning and end of the run, the reduction of water in the tank measured the leak over the system. This trial was made at 136 lbs. pressure per square inch in the steam-gauge, and the total loss of water from the boiler, engine, condenser, air-pump, feed-pump, steam- and exhaust-pipes, during 8 hours, was found to be 40 lbs.

In the course of this trial, a very slight leakage at the safety-valve was noticed, and it was decided to weigh it. For this purpose a pipe was fitted, connecting the safety-valve with a condensing coil, and a seven hours' trial of the boiler alone was made, the steam-pipe being removed and flanges blanked. The steam was kept at the same pressure, viz., 136 lbs. per square inch, throughout the trial, and the total loss from the boiler as measured by the fall in the gauge-glass was 43·6 lbs. in 7 hours. Of this quantity 17·9 lbs. was caught from the safety-valve, the balance being probably due to minute leakages; one or two of these were located, but were too trifling to need a remedy.

These two trials taken together showed that the leakage in the system was inappreciable, apart from the boiler; but, as the amount of the safety-valve leak was not determined in the engine and boiler trial, another trial was made at the same pressure—136 lbs. per square inch in the gauge. This trial was made in the first instance for 8 hours with the engine and boiler at work.

After the engine had been started, but just before the beginning of the trial, the feed-pump, which sucked from the weighing-tank, was shut off, and the water was allowed to fall in the glass until it reached a certain mark. The water in the tank was weighed at that moment—7.39 A.M.—and the trial was commenced. At intervals during the 8 hours, the pump was shut off, the water being allowed to fall to the point in the glass which had been noted at the start; the weight of water in the tank was taken at the instant this occurred, and the leak from the safety-valve was also weighed. The results of these measurements were as follows:—

BOILER AND ENGINE TRIAL FOR LEAKAGE.¹

Jan. 30th, 1892.

Time.			Weight in Tank.	Observed Loss.	Caught from Safety-Valve.	Loss not including Leak from Safety-Valve.
Hours.	Minutes	Seconds.	Lbs.	Lbs.	Lbs.	Lbs.
7	39	1	4,590	..	..	..
10	27	30	4,571	19	11.9	7.1
10	53	17	4,570	1	2.25	- 1.25
12	53	0	4,554	16	7.25	8.75
1	50	0	4,550	4	3.25	0.75
3	6	0	4,542	8	4.5	3.5
3	57	0	4,537	5	1.5	3.5
Total for run				53	30.65	22.35 in 8 hours 17 minutes 59 seconds.

Boiler pressure 136 lbs. in the gauge.

The results are plotted on *Fig. 26*.

From this it will be seen that the net loss over the whole system for 8 hours 18 minutes run was 22.35 lbs., i.e., 2.7 lbs. per hour. This quantity is hardly appreciable as a percentage in most of the trials. In the particular case tested, the average rate of flow was 330 lbs. of water for 24,000 revolutions. The total number of revolutions run during the trial was 205,019, and the whole water used was about 2,820 lbs. The unmeasured leak over the system was therefore about 1.9 per cent.

To determine whether this leak should be debited to the engine or boiler, a boiler-trial was made; the flanges connecting the boiler with the engine and pump were blanked, and the fall in the gauge-glass fitted with a scale, which had been calibrated during the previous trial, was measured during 5 hours. The water lost proved to be 18.4 lbs. in the 5 hours, and during this period 8 lbs. were caught from the safety-valve. The pressure in the boiler was kept as nearly as possible constant at 136 lbs. per square inch gauge-pressure, as in the previous trial; so that the loss by boiler-leakage other than that from the safety-valve was probably not different in the two cases. In the engine-and-boiler trial, the net loss was 2.7 lbs. per hour, and in this boiler trial taken by itself,

¹[The apparent irregularities (excluding one case where the measurements were very small and the time short) are not great relatively to the large weight of water under observation (the tank contained over 2 tons).

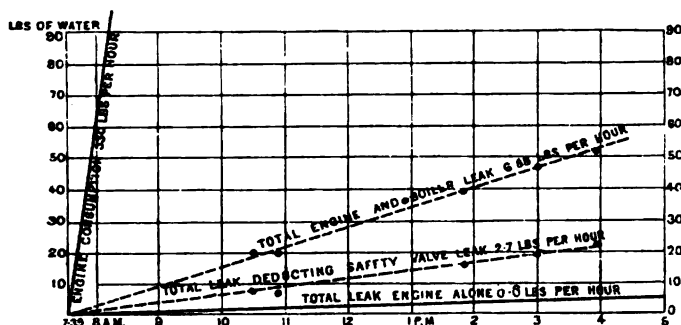
the net loss was 2.1 lbs. per hour. The difference (0.6 lb. per hour) is so insignificant that the Author has not corrected the figures in the Tables.

This matter, which to many may seem of only academic interest, has been thus closely examined, because it is sometimes stated that differences between the boiler-feed and hot-well discharge as great as 5, 10, and even 15 per cent., are of constant occurrence; and this record is sufficient to show that such is not necessarily the case—at any rate with the pressure at 136 lbs. per square inch at the gauge. It should be stated that the condenser was tested immediately before this trial, and was found to be perfectly tight.

In investigating this question the Author was much struck by the extremely small outward indication which a leak of high-pressure steam gives. A leak of water can generally be detected by the deposit left where it occurs; but a minute leak of high-

Fig. 26.

ENGINE- AND BOILER-TRIALS FOR LEAKAGE.



pressure steam is almost invisible, and, even in the open air, can hardly be detected unless condensed on a piece of cold metal. The safety-valve leak to which allusion has been made, would certainly not have attracted ordinary attention. Leaks into the hot atmosphere over and around a boiler usually escape detection by the eye, and grave errors frequently result. The Author would hesitate to say that, if absolute accuracy is required, this method of ascertaining the steam used is applicable to engines in which piston- and valve-rods are continually passing from the cylinder into the outer air; but for a closed engine in which the crank-chamber is thoroughly isolated from the cylinders, the method is the most accurate known to him. In no other way can results be repeated

many times with certainty, unless an amount of care and attention is bestowed on the steam-pipes and boiler connections, which it is not always practicable to give.

SECTION D.

DESCRIPTION OF A SERIES OF SPEED-TRIALS.

Much difficulty has been experienced in comparing the results of trials made at various speeds with those which might theoretically be expected. It has been repeatedly stated that the rate of the initial condensation should, other things being equal, be directly proportional to the square root of the number of revolutions per minute; but this is not always the case in practice. In the Author's non-condensing trials, the results were to all appearance inconsistent. In the compound trials, after making every possible allowance for errors of observation, it would have been impossible to bring the results into agreement with the above law. In the simple trials, on the other hand, the results were fairly consistent with it. The method of making the trials now under review ensured extreme accuracy, and the Author planned a series of some 18 trials, mainly in order to throw light on this particular point. The results are remarkable and worthy of close attention. The compound speed-trials are not important on account of their economical results, for they were made under conditions (5 to 6 expansions and steam-pressure not exceeding 130 lbs. per square inch) unfavourable to high economy; but they will be found to throw light on the causes which contribute to initial condensation.

The trials were made at various speeds, the first group containing trials—

M ₂ , K ₂ , P ₂ , L ₂ , U ₂ ,	made at about	. .	400	revolutions per minute.
Z ₂ , W ₂ , O ₂ , Q ₂ , X ₂ ,	" "	. .	300	" "
T ₂ , A ₂ , D ₂ , Y ₂ ,	" "	. .	200	" "
V ₂ , B ₂ , C ₂ ,	" "	. .	100	" "

Fig. 27, Plate 2, shows on one diagram the total water per running hour (full lines), and the total water accounted for by the high-pressure indicator at cut-off (dotted lines). These lines are the same as those given in Figs. 14 to 17, Plate 1, already described; the shaded interval between the total-water line and

that for water accounted for at high-pressure cut-off, is therefore the missing steam at cut-off, or, more accurately, it represents that quantity corrected by the straight-line method to eliminate small inconsistencies. The vertical height of the shaded interval, denoting the total steam initially condensed per hour, is—

						Lbs.
At 50 lbs. per square inch mean pressure and 400 revolutions . .						70
„ 50	„	„	„	300	„	59
„ 50	„	„	„	200	„	48
„ 50	„	„	„	100	„	34

The last quantity requires to be corrected, for the speed was not in reality so low as 100—115 would be nearer; and, multiplying 34 lbs. by 1.15 the four quantities—70 lbs., 59 lbs., 48 lbs., and 39 lbs. are obtained. These figures appear to vary very nearly as the square root of the number of revolutions per minute, but, as the higher end of the scale of mean pressures is left, and the same comparison is instituted at 25 lbs. per square inch, and at 10 lbs. per square inch mean pressure, a uniform change is found to be in process. The total condensation per unit of time, which at the highest powers is directly proportional to the square root of the revolutions per minute, becomes more and more nearly the same quantity at all speeds, and finally, at quite low powers, the law would appear to be reversed, for the total condensation per unit of time becomes greater than that at high speeds. Thus, though with diminishing horse-power, the total consumption of water goes on diminishing, that part of it which is initially condensed increases, not only relatively, but absolutely. A small constant deduction from the quantities given ought, perhaps, to be made for radiation and conduction up to the point of cut-off, but this does not materially affect the results.

In considering the corresponding quantities for the low-pressure cylinder, the same accurate information as to the quantity of steam entering the cylinder is not available; the latest information as to the quantity of steam present being at the point of release in the high-pressure cylinder. Since that point was reached, radiation and conduction have no doubt diminished it, but re-evaporation, during the high-pressure exhaust, may possibly have balanced this to some extent.

On Fig. 28 the full lines are those for steam present at high-pressure release, taken from Figs. 14 to 17, and the dotted lines are those for steam present at the low-pressure cut-off, from the same diagrams. The shaded interval represents condensation in the

low-pressure cylinder so far as it can be ascertained, and the quantities are—

					Lbs.
At 50 lbs. mean pressure and 400 revolutions	.	.	.	.	133
" 50 " " 300 "	.	.	.	.	118
" 50 " " 200 "	.	.	.	.	105
" 50 " " 100 "	.	.	.	.	70
Or, corrected for 115 "	.	.	.	.	80

These quantities require a deduction of about 20 lbs. to be made before they can be made to vary with the square root of the revolutions per minute; but the difference between the temperature of the steam in the receiver at the top of the cylinder, and that in the exhaust-chamber at the bottom, is considerable, being for trial M_2 about 170° ; and it does not seem improbable that the quantity of heat necessary to account for the condensation of 20 lbs. of steam per hour, may pass down the walls of the low-pressure cylinder. In any case, the matter is mainly one of conjecture, as the actual quantity of steam entering the low-pressure cylinder as steam is not known with certainty.

Turning to the lower part of the scale of power or mean pressure on Fig. 28 it will be seen that there is not, in the low-pressure cylinder, any such great increase of initial condensation as occurs in the high-pressure cylinder, when low speed is combined with low mean pressure. On the contrary, between 50 lbs. and 10 lbs. per square inch mean pressure, the percentage of steam condensed does not vary greatly for each speed, although the tendency is slightly in the same direction as in the case of the high-pressure cylinder. The cause of this difference may possibly be that the greater fall of pressure at the toe of the low-pressure diagram permits the drying of the cylinder-walls to be more thoroughly accomplished during exhaust than in the high-pressure cylinder. On this point, lines 67 and 68, for the fall in pressure in the high-pressure cylinder, and lines 72 and 73, for the fall in pressure in the low-pressure cylinder, should be compared. The measurement of the cushion-steam in the two cases also throws light on the subject. It is given in lines 95 and 96 for the high-pressure, and in lines 101 and 102 for the low-pressure cylinder; from which the condensation during compression appears to be greater in the former than in the latter.

In 1889, during a discussion on the trials of the engines of the "Meteor," at a meeting of the Institution of Mechanical Engineers,¹ the Author gave an account of his experience with an engine of

¹ Proceedings, Inst. Mech. Engineers, 1889, p. 260.

another design, in which water accumulated in the low-pressure cylinder, and in which the addition of a small copper pipe, acting merely locally in the pool of water in the cylinder, was sufficient to turn the scale and prevent its accumulation. In that case, it happened that the balance was so delicate that it was only necessary to turn the steam through the little pipe perhaps once in an hour or two. When the engine was connected to a condenser, no accumulation could be caused to take place under any circumstances. The trials now described, however, show that, in an engine which possesses (like the central-valve engine) great facilities for ejecting water, the effect of gradually reduced speed, coupled with a diminished fall of pressure (*i.e.*, less boiling off) during exhaust may be—not to introduce unstable conditions as above described, although the actual quantity of water present may vary from time to time, but to allow a gradual increase of the amount of permanent water in the cylinder to take place; to permit, as it were, a thickening of the average film on the cylinder walls.

In this connection, it may be mentioned that the amount of water in the cylinders of this particular engine appears to vary in the course of a trial. In the low-speed trials made at 100 revolutions per minute, and 5 expansions, water was undoubtedly present, and in the trials made at 100 revolutions per minute, and 15 expansions, the diagrams were on this account so difficult to take, that the results have not been thought worth recording. In these low-speed trials, at high ratios of expansion, it was necessary to take 2 or 3 diagrams before a legible one was obtained, and it is believed by the Author that the diagrams actually retained are likely to give a higher power than they ought.

Another fact, which points to the presence of a film of water in the high-pressure cylinder during exhaust, is the difficulty sometimes experienced with the piston-rings, especially when the boiler-steam is wet. The rings seem, on the up-stroke, to overrun the film of water, and, on the admission of steam to the cylinder, the steam-pressure acting on this film causes the piston rings to be compressed, and the ends to butt with a clicking noise. This difficulty has been surmounted by the use of steam-packed piston-rings; but, without that precaution, it invariably occurs when the expansion is great, or the steam, from other causes, is wet. When the rings are not steam-packed, the butting can be caused almost always by passing a large quantity of oil through the engine, thus creating a film of oil on the surface of the cylinder. The Author, therefore, believes that this is also the case when water

is present, and the clicking is heard. The possibility of water remaining in the cylinder, was disputed during the discussion on the non-condensing trials alluded to, but since that time he has proved conclusively that under certain circumstances it may, and does, remain there.

The effect of the density of the steam in increasing the condensation at the same range of temperature, can be traced in the 400-revolutions trials, and also in the 300-revolutions trials at 4·8 expansions; that is to say, in those trials in which water remaining in the cylinder is probably of less importance. The effect appears to be lost when working with the same ratio of expansion at 200 revolutions and 100 revolutions per minute.

The figures for the speed trials made at 15·5 expansions, and at 400, 300, and 200 revolutions per minute, are also plotted on Figs. 29 and 30. They show a change, as the power is reduced, of the same general character as those at 4·8 expansions, but it is not so strongly marked. They were not made in sufficient number to warrant such importance being attached to the points denoting the indicated-steam present at various stages, as was the case in the 4·8-expansions trials.

SECTION E.

THE LOSSES LOCALISED ON THE $\theta \phi$ DIAGRAM.

The question as to how much steam on an average is absent during the expansive part of the stroke, in excess of that due to the conversion of heat into work, is important, and can be answered thus:—

First assume 1 lb. of dry saturated steam to be admitted at temperature T_1 to a non-conducting cylinder without clearance, and suppose the whole of the water formed during expansion to be carried away with the exhaust, so as to leave the cylinder dry. The steam would then expand adiabatically, the whole of it would be present at cut-off, and, at any later stage, say when the steam had reached T_2 , the percentage of steam present X_2 would be

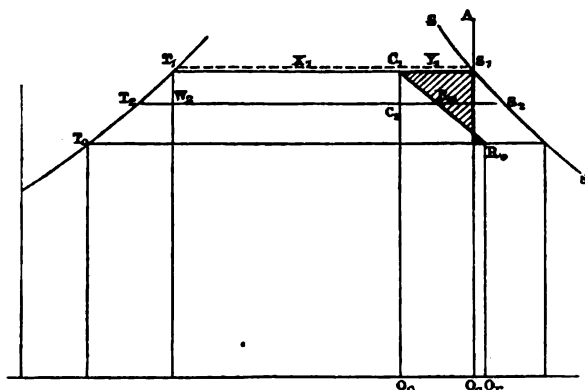
$$\left(\log. \frac{T_1}{T_2} + \frac{L_1}{T_1} \right) \div \frac{L_2}{T_2}.$$

It is well known that in no cylinder does the steam behave in the manner indicated—for a great deal of the incoming

heat is imparted to the iron walls, or to the contained water, or to both; and part of this heat is, under almost all circumstances, returned at later stages of the expansion. It will be well to take an ideal case of the abstraction and return of heat, and then to compare the actual action of the steam with this ideal.

Suppose, then, that instead of the prevalence of strictly adiabatic conditions, the cylinder has a thin liner of material of infinite conductivity, but that the shell is still non-conducting. Assume this liner to be raised from the temperature of exhaust to that of cut-off during the period of admission, and that its temperature agrees with that of the steam at all stages of the expansion. What would be the effect, as shown on the $\theta \phi$ diagram, of such a liner in a non-conducting cylinder? First, assume that 1 lb. of dry steam is admitted to the cylinder, and that the weight of the liner is such that it may, for arithmetical convenience, be considered as equivalent to 1 lb. of water—so that if it is raised 1° in tempera-

Fig. 31.



ture, one heat-unit is abstracted from the incoming steam. The initial and final temperatures being T_1 and T_0 , enough heat must be abstracted from the 1 lb. of steam to raise 1 lb. of water from T_1 to T_0 . Hence the fraction of the 1 lb. of steam condensed, would be (the specific heat of water being unity) $\frac{T_1 - T_0}{L_1}$.

Now, referring to Fig. 31, take $C_1 S_1 = \frac{T_1 - T_0}{L_1} \times T_1 S_1$, and draw the vertical $C_1 O_1$; plot the curve $C_1 R_1 R_0$ similar to $T_1 T_2 T_0$, making $C_2 R_2 = T_2 W_2$, and so on; then x_2 , the fraction of the

1 lb. of steam present at any later stage of temperature in the expansion T_2 , will be

$$x_2 = \overline{T_2 R_2} \div \overline{T_2 S_2} = \left(\log. \frac{T_1}{T_2} + \frac{x_1 L_1}{T_1} + \log. \frac{T_1}{T_2} \right) \div \frac{L_2}{T_2},$$

or, on the $\theta \phi$ diagram,

$$(\overline{T_2 W_2} + \overline{T_1 C_1} + \overline{C_2 R_2}) \div \overline{T_2 S_2}.$$

The hatched area, less the corner shown black at R_0 , is the loss from initial condensation and retarded evaporation under these ideal conditions.

If the metal liner, or its equivalent in the shape of water, be doubled, so that the equivalent of 2 lbs. of water is assumed to be heated from T_1 to T_2 , the heat abstracted from the entering steam will be doubled; and the abscissæ of the curve $C_1 R_2 R_0$ measured from the vertical $C_1 O_0$ must be doubled also, the vertical $C_1 O_0$ being of course further to the left than shown on the diagram. The percentage of steam at T_2 would under these conditions be given by the expression

$$x_2 = \left(\log. \frac{T_1}{T_2} + \frac{x_1 L_1}{T_1} + 2 \log. \frac{T_1}{T_2} \right) \div \frac{L_2}{T_2}.$$

Hence, generally, if R is the ratio

$$\frac{\text{Heat-units abstracted up to cut-off}}{T_1 - T_0},$$

$$x_2 = \left[\left(1 + R \right) \log. \frac{T_1}{T_2} + \frac{x_1 L_1}{T_1} \right] \div \frac{L_2}{T_2}.$$

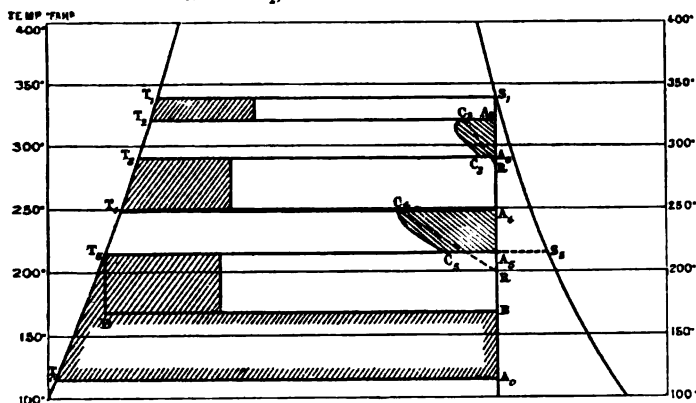
The foregoing represents a purely ideal state of things; but it should represent approximately the action of the permanent water, or of the innermost film of metal, in a cylinder in which the period of each cycle is so short that the losses from radiation and conduction may be neglected; and a comparison between this ideal state of things and the actual behaviour of steam in the cylinder, may possibly be useful in pointing to a conclusion as to the causes of the loss in the various cylinders under different conditions.

In the comparison about to be made, it will be assumed that the steam shown by the indicator to be present at the end of compression is saturated; and that a corresponding weight of steam may be deducted from the indicated steam in order to ascertain the amount present at any point (Appendix IV).

The diagram, *Fig. 32*, has been constructed for trial W_2 . This

trial was made at 300 revolutions and about 6 expansions. It has been chosen for illustration because the observed points for indicated steam on the straight-line diagram, Fig. 15, fall almost exactly on the mean lines drawn through the various points. No correction has been made for the slight divergence from the straight line. In the case of this trial, the temperature in the steam chest T_1 was 338° , and the temperature in the exhaust chamber T_0 was about 114° . The energy in heat-units theoretically obtained from 1 lb. of steam expanded from T_1 to T_0 , and discharged at the latter temperature, is represented by the area $T_1 S_1 A_0 T_0$ on the $\theta \phi$ diagram. This area may be divided into five main divisions: (1) the horizontal band between T_1 and T_2 , i.e., the area $T_1 S_1 A_2 T_2$, representing the amount of work theoretically

Fig. 32.

TRIAL W_2 , ABOUT 311 REVOLUTIONS.

obtainable between the temperature in the steam-chest and that at high-pressure cut-off; (2) the band between T_2 and T_3 , i.e., the area $T_2 A_2 A_3 T_3$, representing the work obtainable between the temperature of cut-off in the high-pressure cylinder, and that of release in the same cylinder; (3) the band represented by the area $T_3 A_3 A_4 T_4$, representing the work obtainable between the temperature of release in the high-pressure cylinder, and that of cut-off in the low-pressure cylinder; (4) the band $T_4 A_4 A_5 T_5$, representing the work obtainable between the temperatures of cut-off and of release in the low-pressure cylinder; and (5) the band $T_5 A_5 A_0 T_0$, representing the work obtainable between the temperature of release in the low-pressure cylinder and that in the exhaust-chamber of the engine.

The hatched areas represent the work lost from various causes, and the large area at the bottom, which is hatched round the edge, only represents the work lost by incomplete expansion; the plain areas represent the work as shown by the indicator diagrams. The part hatched in the uppermost band is the work lost on account of wire-drawing in the steam-ports. The position of this hatched portion has no particular meaning, its area only being of importance. The hatched portion of the second band represents the work lost on account of heat transferred to the metal, or permanent water up to T_2 , the cut-off temperature. The dotted curve $C_2 R$ gives the period at which this heat ought to have returned, if it had followed the ideal conditions considered in the earlier part of this section; and the departure of the actual curve from the ideal curve is a measure of the delay in the return of the heat to the steam. There is a minute loss in the second band due to cushioning, but it is too small to be shown on the diagram. The hatched area to the left in the third band represents the losses between release in the high-pressure, and cut-off in the low-pressure, cylinder. It includes the passage losses between the high-pressure cylinder and the receiver, also between the receiver and the low-pressure cylinder, and other losses, such as a drop at the toe of the high-pressure diagram, etc. The hatched area in the fourth band indicates the losses due to abstraction of heat by the walls of the low-pressure cylinder, or by permanent water—the dotted curve $C_4 R$ representing the ideal return of such heat, as already described.

In the case of the fifth band some explanation will be necessary. The area $T_5 A_5 B B$ represents the energy which would be obtained from the pound of steam if, without any passage- or other losses, the pressure were instantly reduced at release to the pressure corresponding with the temperature T_0 observed in the exhaust chamber. The fraction of the pound of steam which should, after adiabatic expansion from T_1 to T_5 , still be steam at the latter temperature, is represented by $\frac{T_5 A_5}{T_5 S_5}$. The energy remaining in this fraction of the pound of steam may be divided into two parts; (1) the $p v$ energy which may be recovered if the steam be allowed to exhaust suddenly into perfect vacuum; and (2) the internal energy which cannot be recovered unless the steam is allowed to expand to perfect vacuum. If, then, the heat that is latent in the steam remaining (represented by the parallelogram beneath the line $T_5 A_5$ down to the absolute zero of temperature) be divided in the ratio which the $p v$ energy bears to the internal energy

at T_5 , the fraction representing the $p v$ energy will be the part which is recoverable. This part again must be reduced by the extent to which the actual vacuum represented by T_5 falls short of a perfect vacuum; the remainder is represented by the area $T_5 A_5 B B$. The hatched area to the left (its position is im-

Fig. 33.

TRIAL C₂, ABOUT 112·5 REVOLUTIONS.

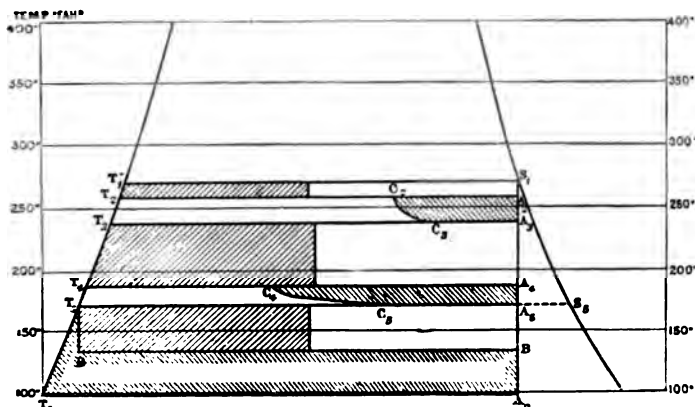
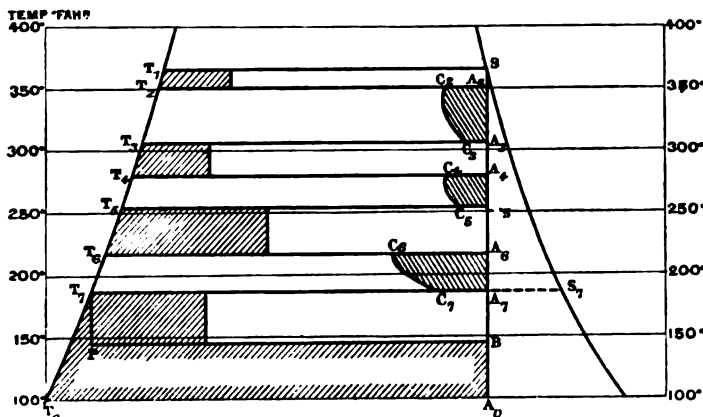


Fig. 34.

TRIAL E₁, ABOUT 380 REVOLUTIONS.



material) represents passage- and other losses of which the principal is probably that due to the defect in volume of the steam at T_5 , owing to the fact that the heat abstracted by the cylinder-walls or permanent water has not been by any means all returned ;

the heat which has not been returned from the cylinder-walls or water at T_5 , the temperature of release in the low-pressure cylinder, is represented by the area below the line $C_5 A_5$ down to zero absolute pressure.

The Author does not think it possible to give in any other way such a graphic representation of the losses in the cylinders as is obtained by this method. A glance is sufficient to show the extent of the losses from incomplete expansion. It will be seen that in the trial W_2 the return of the heat from the walls follows pretty closely the ideal case considered earlier.

Turning to *Fig. 33*, which shows the corresponding losses in the case of the slow-speed low-power trial C_3 , the difference in the character and amount of the losses will be at once apparent. The losses due to incomplete expansion are in this much reduced, but those due to initial condensation are enormously increased. *Fig. 34* gives the results in the same way for the triple trial E_4 , made at 380 revolutions.

SECTION F.

THE ECONOMICAL VALUE OF AUTOMATIC EXPANSION-GEAR AS A MEANS OF REDUCING THE POWER.

The economical value of automatic expansion-gear is usually much exaggerated, and the merits of Corliss valve-gear and of other methods of varying the power by changing the ratio of expansion, have been extolled until it has almost come to be believed that the control of the cut-off by the governor has some occult effect on economy, even when the load does not vary.

The facts generally appear to be these. When the Corliss valve-gear was first used, the pressures employed were comparatively low, and the gain, when the power was reduced by increased expansion, far exceeded the losses from relatively increased radiation, increased conduction, and increased initial condensation, when the results were compared with the other method of reducing the load by means of throttling; moreover, the simple engines upon which the gear was first fitted, were capable of taking the low-pressure steam then employed for the whole stroke, when the full load occasionally came on. The comparison was, therefore, between a throttled engine, hardly expanding at all at full load, and consequently using very low-pressure steam almost un-expansively when running at light loads, and an engine doing

its ordinary load with perhaps a three-fold or four-fold expansion. Under such circumstances, the automatic cut-off engine showed marked economy at ordinary loads. As pressures increased, and engines were compounded, the ratio of expansion necessitated by the use of 2 or of 3 cylinders in series, approached more and more closely to that (sooner or later reached in all engines) beyond which there is no improvement in economy. Hence the economical value of automatic expansion necessarily became less and less.

In connection with this subject, Figs. 35, 36, 37, Plate 2, contain the comparative results obtained from trials at various expansions for the simple, the compound, and the triple engine. In the case of the simple engine, progressive trials were made with ratios of expansions of 2 and 4 approximately.

The ratio of the cylinders and the action of the valve-motion of the compound engine made it impossible to expand less than about 5 times. Three series of progressive trials were made, and are plotted for comparison in Fig. 36; the nominal ratios of expansion in these 3 groups were approximately 4.8, 10, and 15.5. Under these conditions w , the water required by the "frictionless" engine to run at a speed of 400 revolutions per minute, will be seen to steadily increase with increasing expansion, while K , the factor which determines the subsequent cost per HP., decreases. The straight lines cross at points x and x_1 , the positions of these points advancing along the power base as the expansion increases; and from the diagram it will be seen that below about 5 lbs. mean pressure, no gain is derived from the use of 10 expansions over 4.8 expansions; whilst below about 11 lbs. mean pressure, no gain is derived from the use of 15.5 expansions over 10 expansions. Two trials were made at 20 expansions, but no appreciable advantage over 15.5 expansions could be observed, and it is probable that, beyond that point, a loss may take place. Each of the straight lines in Fig. 36, Plate 2, is divided so as to form a scale of pressure, in the manner described in section C. The scale is necessarily closer when 15.5 expansions are employed than in the case of 10 and 4.8 expansions.

If, now, the engine is arranged to give full load with steam of 130 lbs. pressure per square inch (absolute) and 4.8 expansions, and the power of the engine is reduced by lowering the pressure, the figures for total water-consumption per hour are found, as has been already shown, to lie along the straight line for 4.8 expansions. When, on the other hand, the power is reduced by altering the cut-off, and keeping, say, 170 lbs. pressure per square inch (absolute) in the steam-chest of the engine, the corresponding

points for total water-consumption will lie on a constant-pressure curve obtained by joining the points indicating 170 lbs. on the scales on the 3 straight lines (Fig. 36). The vertical height between the curve and the straight line indicates the gain in steam per hour at any load, due to the reduction of power by increasing the expansion as compared with that effected by reducing the pressure. For instance, in Fig. 38, the curve of constant pressure cuts the straight line of constant cut-off in two places, and there is, therefore, only a gain at medium loads; at high and at low loads the consumption of steam is greater.

In the triple trials, the ratio of the cylinders, and the valve-motion, made it impossible to make tests with less than 12 expansions; and the gain by expanding 20 times, as compared with 12 times, being very slight, the results of these two series of trials only are compared (Fig. 37).

Thus it is found (as the Author has previously shown on theoretical grounds to be probable) that, in the case of an engine working comparatively non-expansively at full load, like the simple engine, the gain by cutting off earlier in order to reduce the load is great. In the compound engine, on the other hand, the gain rapidly decreases as the ratio of expansion at full load increases; whilst in the triple engine, the economical value of automatic expansion-gear is almost inappreciable. The question apparently turns on the question of the load at which the normal work is done.

On an electric railway using compound engines necessarily working under a fluctuating load, it is probably desirable to use automatic expansion-gear; because, by that means, engines, arranged to work at an economical ratio of expansion at their normal load, may be made to give off momentarily much greater power at a slightly increased cost. In central electric-lighting stations it should be the aim of the engineer to so arrange the size of his generating units that the engines at work may be at all times, as far as possible, fully loaded. Under these conditions, any slight gain, when the power is reduced due to the action of automatic expansion-gear, is not of vital importance; seeing that it is the gain due to one only among a number of engines—especially as the gain seems almost to disappear when high-pressures and triple-expansion engines can be used together.

One more question remains in this connection; does this law hold good at low as well as at high speeds? The answer afforded by these trials is clear and explicit. The law limiting the number of expansions comes into operation sooner at low than at high

speeds. Fig. 39, Plate 2, shows this quite clearly. On this diagram, the total water used at 6 expansions is compared with that at 16 expansions. The gain at the highest point in the power-scale is

	Lbs.
At 400 revolutions	139
„ 300 „	80
„ 200 „	36

In other words, the gain at 200 revolutions is only half what it is at 400 revolutions, after allowing for the difference in horsepower consequent on the reduced number of revolutions. The whole of the trials enumerated so far, have been made with steam known, by comparison of the pressure-gauge and thermometer in the steam-chest, not to be super-heated. This is unfavourable to the case of the throttled-engine, for if the steam be dry as it leaves the separator, it must be super-heated when it enters the engine.

CONCLUSION.

The engine with which these trials have been made does not differ, except as regards the valve motion, from the ordinary engines built at Messrs. Willans and Robinson's works, the various parts having been taken from store, so far as they were adapted for the condensing trials. It is the first engine which has been made specially for condensing work,¹ and naturally the series of trials just described has suggested some minor improvements, but, as in the case of the former non-condensing trials, no alterations were made in the course of the experiments. Comparing the results of the triple trials now described with those of the triple non-condensing trials, it will be seen that, after allowing for the comparatively large loss due to incomplete expansion, the percentage of available energy obtained is not very different in these from what it was in the non-condensing trials. The best efficiencies in the case of the non-condensing trials were about 78 per cent. with the triple engine. In the condensing trials, the highest thermal efficiency obtained has been about 63 per cent., leaving a balance in favour of the non-condensing trials of about 15 per cent. of the work theoretically due from the steam. Almost the whole of this deficiency is due to the greater losses from incomplete expansion in the condensing trials. A further small part of the

¹ Previously the same standard pattern was used for condensing and for non-condensing.

difference is due to the fact that, in these trials, the temperature in the steam-chest has been taken as the higher limit T_1 , whilst in the non-condensing trials, the temperature due to the mean admission pressure was taken. With respect to loss from incomplete expansion, the Author thinks that it is not possible with the steam-engine, as it now stands, to look forward to any great reduction; and it should be noted that as lower temperatures are used, the steam-engine, must necessarily give a reduced efficiency when its duty is compared with the work theoretically obtainable.

In one or two trials made with regard to the questions of superheating and steam-jacketing as a means of increasing the economy of the engine, a slight advantage is shown to be gained by jacketing; but only extended experiments can show whether this gain is likely to be worth the extra trouble and expense involved by it. The problem in the case of an engine working at a large number of revolutions is so different from that which has been attacked by the makers of slow-speed engines, and the possible gain so much smaller, that the Author has not been able to form any definite opinion on the subject.

Comparing these trials with those made on the non-condensing engine, the following points are noticeable:

(1) The steam missing at cut-off is seen to vary to a somewhat greater extent than it did in the non-condensing trials.

(2) Its amount is shown to be largely affected, as in the former series, by the range of temperature in the cylinder; but at the same time it would appear to be clear, in the present case, that the density of the steam possesses, under certain conditions, great influence; this is to be expected if the walls are dry. There is one broad difference between the high-pressure diagrams in the case of these trials, and in those for the non-condensing series; almost all the high-speed trials in the latter case had loops at the toe of the diagram in the triple and compound series. In the present case these loops are, on account of slight alterations in the valve-motion, not present. The trials at 300 revolutions per minute were not made in the case of the non-condensing series, but the results, as plotted on the curves, did not indicate that any considerable difference would be likely to arise between the consumption at 400 and that at 300 revolutions per minute. The trials now under review show, that in this particular engine, the economy does not very greatly vary between these two speeds, but that below 300 revolutions it begins to fall off.

It is hardly possible to define, for a condensing engine, the

best ratio of expansion. This question must remain one for each particular engine-builder to answer. The useful work obtainable from the steam depends so greatly on the condenser back-pressure, and on the friction of each individual engine, that it is impossible to give any general rule. It is practically certain, however, that the ratio of expansion should not exceed the limit given in *Fig. 5*.

It would appear that, under almost all circumstances, the triple condensing-engine shows an advantage over the compound one in point of steam-consumption, the range of temperature in the former being so much greater; at the same time, it is evident that it is not economical to employ a third stage of expansion unless some considerable gain results; and it is probable that, for pressures below 150 lbs. per square inch, the compound engine with the transfer arrangement is the best except, perhaps, in the case of very large engines.

As to the percentage of work due from the steam entering the cylinder, and remaining steam at cut-off, which is the measure of what has been called "plant efficiency," it has been shown that this does not vary greatly from what it was in the non-condensing trials.

The Paper is accompanied by a large number of diagrams from which Plates 1 and 2 and the *Figs.* in the text have been prepared.

APPENDIXES.

APPENDIX I.

CONSUMPTION-TRIAL.

Trial . . . C $\frac{130}{10}$ 400 Reference to trial records . E.

Engine No. 1. Size, 14 inches by 6 inches. Barometer, 29·775 inches.

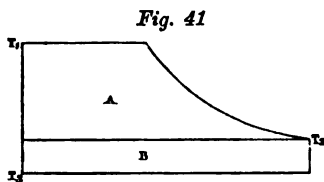
Engine-room temperature, 70° Fahrenheit. Intended revolutions, 400.

Date, December 2, 1892.

Weight in Tank.	Time.			100 Lbs. Interval.	Counter Reading.	Running Time.	Steam Chest Pressure Gauge.	Steam Chest Temperature Observed.	Exhaust Temperature Observed.	Vacuum in Condenser.	Diagram Number.
Lbs.	Hrs.	Mins.	Secs.	Mins. Secs.				°	°		
2,300	2	42	12		745,000	..	125	352	114	27·65	
2,400	2	56	31	14 19	750,785	14·46	125	351	114	27·7	1
2,500	3	10	39	14 8	756,491	14·26	125	351	113	27·7	2
2,600	3	25	19	14 40	762,409	14·79	125	352	113	27·8	3
2,700	3	39	37	14 18	768,205	14·49	125	352	113	27·8	4
2,800	3	54	6	14 29	774,091	14·71	125	351	112	27·8	5
2,900	4	8	23	14 17	779,854	14·41	125	351	112	27·8	6
3,000	4	23	24	15 1	785,730	14·69	125	351	111	27·85	7
3,100	4	38	19	14 55	791,554	14·56	125	352	111	27·9	8
3,200	4	53	18	14 59	797,458	14·76	125	351	111	28·0	9
3,300	5	7	55	14 37	803,247	14·47	125	351	111	28·0	10
3,400	5	22	50	14 55	809,149	14·75	125	351	111	28·0	11
3,500	5	37	37	14 47	814,993	14·61	125	352	112	28·0	12
Mean of all ob- servations . .							125	351·4	112·1	27·84	

1,200 lbs. total steam used. Actual time, 2h. 55m. 25s. = 175·41 minutes.
69,993 total revolutions. Running time, in minutes, at 400 revolutions per
minute, $174·98$. Total water used per running hour = $\frac{1,200 \times 60}{174·98} = 411·47$.

Having thus found T_2 by the process of trial and error on *Fig. 40*, and checked it by the correct formula, the mean pressure is easily calculated from the under-mentioned formulas, which refer to *Fig. 41*.



$$\text{Area A in heat-units} = \frac{L_1}{T_1} (T_1 - T_2) + T_1 - T_2 - T_2 \log \frac{T_1}{T_2} = U^1.$$

$$\text{Mean pressure of A} = \frac{772}{144} \frac{U^1}{V_2}.$$

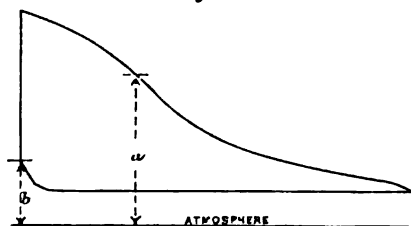
$$\text{Mean pressure of B} = p_2 - p_0.$$

APPENDIX IV.

CALCULATIONS FOR STEAM PRESENT ACCORDING TO THE INDICATOR.

In calculating the steam present at cut-off, the following method has been adopted :—

Fig. 42.



The steam shown to be present in the clearance at the point of admission is assumed to be saturated steam, and the weight of this steam is calculated for the clearance-volume at the pressure *b*. At the point of cut-off, the steam which has been admitted according to the indicator, is the weight of steam represented by the volume swept by the piston up to cut-off at *a* pressure, plus the weight of steam required to raise the clearance-steam from the admission-pressure *b* to the cut-off pressure *a*, the latter being sometimes a positive and sometimes a negative quantity.

The method of making the calculation is shown below :—

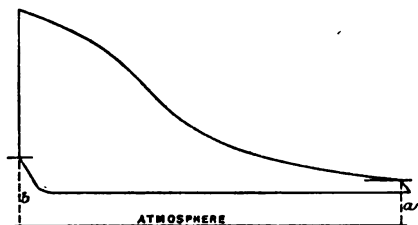
Trial: C $\frac{140}{10}$, 200 Revolutions. Date, 3rd December, 1891. HP. Cylinder.
Point of cut-off.

$$\begin{aligned}
 X &= \text{Barometric pressure} && = 14\cdot72 \\
 a &= \left\{ \begin{array}{l} \text{Pressure above atmosphere at point of cut-off,} \\ \text{mean of 12 diagrams} \end{array} \right\} && = 96\cdot55 \\
 b &= \left\{ \begin{array}{l} \text{Pressure above atmosphere at point of admission,} \\ \text{mean of 12 diagrams} \end{array} \right\} && = 41\cdot00 \\
 A &= X + a && = 111\cdot27 \\
 B &= X + b && = 55\cdot72 \\
 w_1 &= \text{Weight of steam per cubic foot at A pressure} && = 0\cdot2536 \\
 w_2 &= \text{Weight of steam per cubic foot at B pressure} && = 0\cdot1325 \\
 &w_1 - w_2 && = 0\cdot1211 \\
 W_1 &= \text{Weight of steam accounted for by volume swept by} \\
 &\quad \text{piston} \\
 &= \frac{\text{Point of cut-off} \times \text{stroke} \times \text{revolutions per hour} \times \text{area} \times w_1}{1728} \\
 &= \frac{0\cdot28 \times 6 \times 12,000 \times 50\cdot25 \times 0\cdot2536}{1728} && = 148\cdot67 \\
 W_2 &= \text{Weight of steam accounted for by cylinder-clearance} \\
 &= \frac{\text{Cylinder-clearance} \times \text{revolutions per hour} \times (w_1 - w_2)}{1728} \\
 &= \frac{22\cdot89 \times 12,000 \times 0\cdot1211}{1728} && = 19\cdot68
 \end{aligned}$$

S	= Total weight of steam accounted for by indicator	
	= $W_1 + W_2$	= 168·35
T	= Water used per hour	= 243·86
$\frac{S}{T}$	= Percentage of water accounted for by indicator	= 69·02
Water missing $\left\{ \begin{array}{l} 75·51 \text{ lbs.} \\ 30·98 \text{ per cent.} \end{array} \right.$		

The calculation for the steam accounted for by the indicator at any later point has been made in a precisely similar manner, as shown in the calculation sheet for the steam-diagram measured at release.

Fig. 43.



Trial : C. $\frac{140}{10}$, 200 revolutions. Date, 3rd December, 1891

H.P cylinder. Point of release.

X	= Barometric pressure	= 14·72
a	= { Pressure above atmosphere at point of release, } mean of 12 diagrams	= 27·15
b	= { Pressure above atmosphere at point of admission, } mean of 12 diagrams	= 41·00
A	= $X + a$	= 41·87
B	= $X + b$	= 55·72
w_1	= Weight of steam per cubic foot at A pressure	= 0·1013
w_2	= Weight of steam per cubic foot at B pressure	= 0·1325
	$w_1 - w_2$	= - 0·0312
W_1	= Weight of steam accounted for by volume swept by piston	

$$= \frac{\text{Point of release} \times \text{stroke} \times \text{revolutions per hour} \times \text{area} \times w_1}{1728}$$

$$= \frac{0·95 \times 6 \times 12,000 \times 50·25 \times 0·1013}{1728} \dots = 201·48$$

W_2 = Weight of steam accounted for by cylinder clearance

$$= \frac{\text{Cylinder clearance} \times \text{revolutions per hour} \times (w_1 - w_2)}{1728}$$

$$= \frac{- 22·89 \times 12,000 \times 0·0312}{1728} \dots = - 5·07$$

S = Total weight of steam accounted for by indicator

$$= W_1 \times W_2 \dots = 196·41$$

T	= Water used per hour	= 243·86
$\frac{S}{T}$	= Percentage of water accounted for by indicator	= 80·54

Water missing $\left\{ \begin{array}{l} 47·45 \text{ lbs.} \\ 19·46 \text{ per cent.} \end{array} \right.$

In the case of the cut-off measurements, the difference between the weight of the steam thus shown to have been admitted, and that of the steam ascertained to have passed through the engine, is the "missing quantity" at cut-off, and this includes steam absent on account of priming, leakage, and radiation up to the point of cut-off.

In Professor Osborne Reynolds' reply to the Author's criticisms on his Paper¹ on "Triple-Expansion Engines and Engine Trials," he objected to this method of measuring the diagrams, holding that the water condensed during compression should be included, by taking the play-steam measurement at an earlier point in the compression curve. The difference between the two is probably unimportant, unless a large quantity of water is present in the cylinder, or unless condensation is excessive for other reasons; but, in any case, the Author's object was to determine the percentage of the feed-water condensed up to the point of cut-off; and would have been wrong to have included in this quantity any part of the play-steam which might happen to have been condensed. He has, therefore, made the calculations for the present series in the same way. In calculating the steam present at release, or at any point, later than cut-off, the best method is not quite so clear. In these cases, a question arises as to whether the reduction in the quantity of play-steam during compression is due to liquefaction or to leakage; and, if to liquefaction, whether the heat abstracted is lost by radiation or conduction, or is given back as the expansion proceeds. If it is lost altogether, the Author's method of making the calculation is strictly accurate, but if it is lost only temporarily, it might possibly be more correct to allow for a larger quantity of play-steam at release than at cut-off. After full consideration, the method described was adopted for the following reasons:—

(1) The quantity of play-steam is very minute, and the measurements are difficult, those at the point of admission being, on the whole, more likely to be accurate than those made earlier in the compression.

(2) Part of the condensation observed is certainly caused by radiation and conduction, and by leakage.

(3) Condensation is not the invariable rule, and the Author did not feel sufficiently certain of the value of the measurements at the earlier stages of compression, as to complicate his methods on account of so small a quantity. The measurements at cut-off are, he thinks, made correctly, but with respect to the measurements at later stages in the expansion, it must be understood that in cases in which condensation goes on during compression, and in which a part of the heat abstracted by the walls or water during that period is restored as the expansion proceeds, a small addition to the missing quantity given in lines 49, 51, 53 ought to be made. In cases where re-evaporation occurs during compression, the correction would be in the other direction.

In order to form some idea of the magnitude of the correction likely to be required, it might be well to consider the case of the 5-expansion compound series at 400 revolutions, given in Table II, where an average condensation of 2·3 per cent. was observed. In this case, the play-steam amounts to about 4·9 per cent. of the steam accounted for at release; so that 2·3 per cent. of the

¹ Minutes of Proceedings Inst. C.E., vol. xcix. p. 152.

play-steam would amount to about 0.1 per cent. of the whole steam accounted for at release. Part of this small quantity might therefore have to be added to the steam missing at release. In the low-pressure cylinder measurements of the above series, a practically constant quantity of play-steam is found during compression, and no correction is needed. In the trials at lower speeds and higher ratios of expansion, the play-steam is sometimes diminished during compression to a greater extent, but as there were no means of ascertaining the cause of the diminution, the Author has treated all trials in the same way. The results of the measurements of the compression-curves are given in the Tables for use by others, if required. In any case, no difference of magnitude is occasioned, and if any, it affects the high-speed trials the least. Professor Osborne Reynolds also criticised the measurements at the point of cut-off in the following words:—"He hoped Mr. Willans would now be induced to make another reduction of his indicator-diagrams by means of the mean diagram, after the method described on page 30. In this case he had no doubt Mr. Willans would find the missing quantity at cut-off in his high-pressure cylinder increased some 6 or 7 per cent. at the higher speeds, and that the cylinder-condensation varied with the square roots of the speed. The trials of Mr. Willans appeared to have been so carefully made, and the engines themselves so admirably adapted to test the effect of speed on cylinder-condensation, that it would be a great pity if the results, instead of furthering knowledge, were allowed to remain a stumbling-block for want of accurate reduction." The Author does not agree with Professor Osborne Reynolds. He knows that in all high-speed diagrams there is a chance of inaccuracy in measuring particular points, but he believes that, in such diagrams, the measurements at the point of cut-off are more likely to be correct than those made at later points in the expansion. The indicator-pencil has then usually recovered from the effect of the vibrations almost unavoidable at admission, and has not commenced its quick descent after the steam-port is closed. The Author sees no reason for revising his previous methods in this respect, more especially as he has, he thinks, shown conclusively that there is no universal law which makes condensation, per unit of time, proportional to the square root of the speed.

APPENDIX V.

THE STANDARD OF PERFECTION USED BY PROFESSOR OSBORNE REYNOLDS.

The Author has always taken for his standard of perfection the whole area of an adiabatic diagram from one pound of steam between the limits of temperature available for the trial, as shown by the dotted area in *Fig. 44*.

Fig. 44.



The full diagram is the one which would be obtained if the steam were maintained, by added heat from the jackets, in the state of saturation throughout. The

absolute efficiency or $\frac{\text{heat utilized}}{\text{heat supplied}}$ is less in the case of the larger diagram, because, although larger, it costs much more to make it. Professor Osborne Reynolds on the other hand, compared his results with the diagram which would be obtained from steam kept in a state of saturation, and not with the full diagram shown above, but with a diagram shortened, so as to bring the pressure and temperature at release to the same point as in the engine, the efficiency of which was to be decided (*Fig. 45*).

Fig. 45.



The Author pointed out,¹ that, if the standard of perfection were to be altered to suit the point of cut-off which happened to be employed in any engine under test, the whole meaning of the term efficiency would be lost, because a donkey-pump or a steam fire-engine carrying its steam throughout the whole stroke, would probably come out the most "efficient" engine in existence—the losses from initial condensation being so very small that the diagram to be expected from each pound of steam would be obtained almost in its entirety.

This is not what the Author means by efficiency, and he does not see how anyone can properly use any other ideal standard of thermal efficiency than the full area of the diagram between the limits of temperature available.

Professor Osborne Reynolds, on page 248, made remarks, which, coming from such a source, and being made at a time when they could not be immediately contradicted, may have left the impression on the minds of many that, to suit his own purpose, the Author had mis-quoted Rankine's formula. These remarks were as follows:—

"Mr. Willans had given a formula, emphatically not Rankine's, had headed 'the results calculated by this formula 'Percentage of Theoretical Efficiency of Rankine's Jacketed Engine,' and placed them immediately over the 'Author's 'percentage of Theoretical Efficiency' (lines W and X). Rankine had given no 'rule for the theoretical efficiency of a jacketed engine, but he gave a formula 'for the efficiency of dry saturated steam, which was the same as was now 'commonly meant by the theoretical efficiency of the jacketed engine. He 'also had given a formula for the heat utilized per lb. of dry saturated steam, 'which was

$$U_1 = a \log_e \frac{T_1}{T_2} - b (T_1 - T_2) + v (p_2 - p_1),$$

"in which the suffix, referred to admission, to release, and, to the condenser. It "was this formula that Mr. Willans had used in concocting his own; he had put "A for T_1 , B for T_2 , and left out the important final term. Nor was this all; in "calculating the results Mr. Willans had, for B or T_2 , the temperature of release, "substituted the temperature of the condenser, which in these trials was some "60° Fahrenheit less than the temperature of release. The Author forbore all "comment on this proceeding on the part of Mr. Willans."

¹ Minutes of Proceedings Inst. C.E., vol. xix. p. 228.

Now, what were the facts? Rankine had given a perfectly general formula.

$$\text{Efficiency } \frac{U^1}{h} = \frac{U_1 - U_2 + v_2 (P_2 - P_1)}{U_1 - U_2 + H_2 - h_1},$$

for the thermal efficiency of steam kept by added heat in a state of saturation; whether he called it a jacketed engine was beside the question.

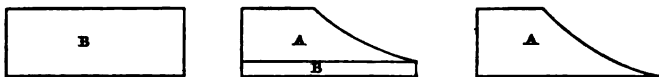
This formula showed, if it showed anything at all, that the area of the diagram bounded by the full lines in *Fig. 44* was greater than the area of the *Fig. 45*, and not only was it greater, but it was larger also in proportion to its cost.

Rankine had certainly not said "Place the smaller area before yourself and your students as an ideal standard of perfection." His formula only said "Under certain conditions this is the efficiency," and it showed that if, for practical reasons the steam was not expanded down to back-pressure, part of the available energy must be lost. The diagram should not be mutilated to suit the circumstances of the case under review.

The formula for the return from each pound of steam is also perfectly general—

$$v^1 = \underbrace{1438 \log \frac{T_1}{T_2} - 0.7 (T_1 - T_2)}_A + \underbrace{V (p_2 - p_1)}_B$$

Figs. 46.



This formula gives the return from a pound of steam whether used expansively or non-expansively. The two areas A + B in *Figs. 46* are lettered to correspond with the letters under the terms in the formula; either A or B may disappear under different conditions. In a non-expansive engine A is zero; in an engine expanding to its own back pressure, B is zero.

In the ideal standard which the Author advocated, "the important final term" B is zero, and he really did not, in criticising Professor Osborne Reynolds' Paper, think it possible that his remarks could be open to such misconstruction.

The above argument applies equally to the adiabatic and the saturation diagrams, but the Author cannot agree that the latter should be in any case taken as the standard of thermal efficiency; although in the jacketed trials, it might be useful to see whether the jackets have the effect of keeping the steam saturated. To compare the results from the un-jacketed engine with the area of the saturated diagram, is, the Author thinks, quite indefensible.

Discussion.

Mr. HARRISON HAYTER, President, said that the Author of the Paper was no longer with them. His life was lost about a year ago, in an unfortunate accident, when he was only about forty years of age, and in robust health. The Institution and the profession had thus been deprived of an able member, and the country of one who had already made his mark as a mechanician and a scientist. In 1885 the Author had given to the Institution a Paper on "The Electrical Regulation of the Speed of Steam-Engines;"¹ and in 1888, another Paper on "Trials of a Non-Condensing Steam-Engine."² The present Paper was related only in a small degree, if at all, to that of 1885; but it might be regarded as a continuation of the Paper of 1888. In the latter communication had been submitted the results of trials of a central-valve engine working non-condensing. The present Paper was devoted to a record of trials with a condensing-engine of the same type. The Paper of 1888, extending over three successive evenings, elicited an interesting discussion; and he hoped that the present Paper would lead to results equally valuable. It was full of information, the result of careful research; and the Tables appended to it were most elaborate. The numerous diagrams showed the pains that had been taken in the preparation of the Paper. If the Author had been present, he would without doubt have received a very cordial vote of thanks from the members. The President could now only express a confident belief, which would be shared by all, that this last effort of the Author would add to his posthumous reputation. Mr. Robinson would open the discussion by a few preliminary remarks.

Mr. MARK H. ROBINSON said that, after the statement of the President, no words were needed from him to tell what the world had lost in the premature death of the Author. Before referring to any of the points raised in the Paper, he would say a few words in anticipatory answer to a question which some writings in the technical press led him to half expect—to what end these innumerable calculations and figures? Would they help the "practical man?" Could they teach him to make a better engine? To those

¹ Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 166.

² *Ibid.*, vol. xciii. p. 128.

Mr. Robinson. questions he answered emphatically, "Yes." Up to a certain point the practical man might ignore the present Paper and others like it; but if he aspired to design economical steam-engines, he might derive more good from the study of, say, Mr. Macfarlane Gray's $\theta\phi$ diagram than from many portfolios of working drawings. Practical use was the object of the Author's experiments. It was to help to perfect his own condensing-engines that they were undertaken, and that end had been largely attained; a wholly new series of central-valve condensing-engines had been designed by the light of the results given in the present Paper, though, unhappily, by other hands than those of the Author. The danger which, as many thought, now threatened English engineering lay in the more thorough education and the superior mathematical knowledge of so many foreign engineers. When there was a break-down to set right in a hurry, or a day's emergency work to be done in an hour, then might he find himself in the hands of an Englishman, but he dared not shut his eyes to the progress of scientific engineering abroad. Essentially a practical engineer, the Author began his work with a distinct prejudice against theory, and against the mathematical treatment of the steam-engine; but he ended by becoming one of the leading exponents of the scientific treatment of the subject, simply because, as a true engineer, he could not but recognize its necessity. Ten years ago, the Author was known as the designer of an ingenious engine, which, in spite of its high speed, was fairly economical and gave marvellously little trouble. When high speed was necessary, and coal was not very important, it was allowed to be just the thing. Five or six years later, by sheer force of scientific work and research, the Willans engine was in a position to challenge the very highest types of slow-running engines for economy, and the unlooked-for truth was established that the faster an engine ran the more economical it ought to be, other things being equal. There were few things in the Paper more interesting than the reasoning respecting the loss by the necessary cutting off of "the toe of the diagram," and the inevitably greater relative loss it produced in a condensing than in a non-condensing engine—a subject which had been fully treated by Prof. Cotterill in the latest edition of his book on the steam-engine.¹ The reasoning was admirably clear, but to those who saw the Paper for the first time, or had not read Prof. Cotterill's book, some aid might be given by a graphic comparison of the two cases. Down to the lower dotted line, Fig. 47 (i.e., down to atmo-

¹ Cotterill, "The Steam-Engine." London, 1890.

spheric pressure), was the ideal diagram which the Author took for the non-condensing engine. On the assumption that it was not worth while in practice to carry expansion below $4\frac{1}{2}$ lbs. above atmospheric pressure, i.e., to an absolute back pressure of about 19.2 lbs., the smaller shaded triangle showed the necessary loss with a non-condensing engine. The same engine turned into a condensing engine (with its cylinder-capacity enlarged as necessary) might conceivably expand down to the Author's theoretical

Fig. 47.

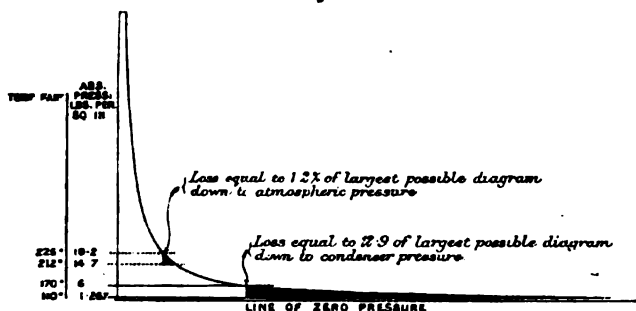
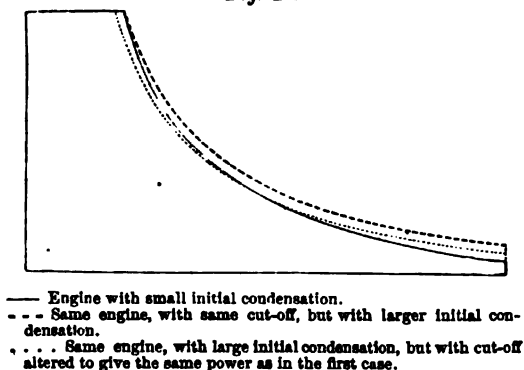


Fig. 48.



back-pressure, viz., that corresponding with 110° F. For that reason, he took the whole diagram down to 1.127 lb. (absolute) as the ideal diagram for a condensing-engine. But he reasoned that, although one might hope to get a condenser which would condense down to 110° F., there was no use in carrying the expansion below 6 lbs. (absolute) at release—170° F.; and this left a relatively large triangle shaded as loss. Thus, whereas the inevitable loss in the non-condensing engine was only 1.2 per cent.

Mr. Robinson of the best possible diagram in the condensing engine there was, perhaps, not an actual necessity, but good practical reason (in order to avoid worse disadvantages) for working with a loss as great as 12·9 per cent. In the diagrams undoubtedly the most noticeable feature was the straight-line law of the total steam-consumption, which his colleague Captain Sankey had asked him to suggest should be called the "Willans" law—a suggestion which he was sure all interested in steam-engine research would endorse. The idea of regarding the total steam used under all conditions, rather than the steam per HP., had proved to be most useful and suggestive. When ascertained facts were recorded by curves, there was usually too much conjecture in the attempt to extend them far in either direction. But when, instead of a curve, a straight line was being dealt with, there need be less hesitation in exploring that part of the field which lay outside the region of experimental knowledge. It might sound paradoxical, but he hoped to run the experimental engine at no mean pressure at all. It would be done by running the dynamo, to which the engine was coupled, as a motor. It would then be seen what steam it took to do nothing—that was, to make good the loss of heat through conduction along the metal, through radiation, and through initial condensation. One of the main objects of the experiments was to settle the best ratio of expansion under various circumstances, but the conclusion expressed was that it was hardly possible to define the best ratio, though it was easy to place a limit to it. In that connection, he would call attention to the fact that the better an engine was, the fewer expansions it required in order to develop a stated power, with a given steam-pressure and a given back-pressure. In *Fig. 48* the full line was intended to represent approximately the expansion curve of a good engine, in the sense of an engine working with small initial condensation and not much re-evaporation. If the engine had a good deal of initial condensation, and consequently larger re-evaporation, expansion might tend to follow the thick black dotted curve. That was what some would call a well-fattened diagram, and they rejoiced over it; but the fattening might cost too much. As only a given HP. was required, the cut-off gear would next make the cut-off earlier, and the expansion-curve would finally assume the position of the thin dotted line. The engine would now work with more expansions, and show less steam present at cut-off. But the total quantity of steam which entered the engine as steam and as water, was larger in that engine than in the one which gave the same power with fewer expansions. He was sure that the Author would, if he had been

present, have expressed his obligations to Mr. Macfarlane Gray Mr. Robinson. for that admirable instrument of research, the $\theta \phi$ diagram, and for the bent towards the scientific treatment of steam-engine problems which he had so largely derived from Mr. Gray's inspiring counsel and help; and he would have referred once more to the help and encouragement he had received from Mr. Crompton, Mr. Druitt Halpin, Prof. Kennedy, Mr. Mair-Rumley, Prof. Unwin, and many others who were never forgotten by him or by his colleagues. If he might be allowed once more to refer to *Fig. 47*, he thought that no one could doubt that, for a non-condensing-engine, the ideal diagram was rightly taken down to the line of atmospheric pressure—14·7 lbs.; but with regard to the condensing engine, to obtain a boundary line equally certain, he was afraid the bottom line of all must be taken—the line of zero pressure. It was impossible, however, to expand down to zero pressure without a cylinder of infinite capacity, and the Author had therefore cast about for some more reasonable boundary to his ideal diagram, and had fixed upon a pressure corresponding with 110° F., as something which might reasonably be obtained in the condenser. Of course, that was an arbitrary limit only; but he wanted to point out that, the line of zero pressure being ruled out, it was necessary to take an arbitrary line; there was no choice. Some might argue for 100°, and some for 105°; but he did not think that any one would argue for 0°. If all would agree to the Author's line, it would be a good thing. Another point had reference to the greater relative area of the shaded triangle representing the necessary loss in the condensing-engine compared with that for the non-condensing engine; he should have explained that this was common to all condensing-engines; it was not in any way peculiar to the Willans engine—Nature was responsible for it. Though the minimum percentage of loss out of the diagram which it was possible to obtain in a condensing-engine was, and must be, larger than the loss in a non-condensing engine, it was better to have a large diagram subject to a loss of 13 per cent., than a diagram only two-thirds as large, subject to no loss at all. In fact, the greater absolute economy of the condensing-engine was in no sense called in question. The loss was in practice inevitable, being imposed by considerations of practical convenience. With regard to the rate of expansion which was justifiable or advantageous, he would point to the results of two triple-expansion engine trials, one G_4 , and the other L_4 , with a steam-pressure of 184 lbs. per square inch in the steam chest, made at the same speed, 400 revolutions per minute. One was with 12·36

Mr. Robinsen, intended expansions, and the other with 20·6 intended expansions, and the results were exactly the same—12·74 lbs. of steam was used per I.H.P. His chief object in directing attention to the matter was to deprecate the conclusion that 20 expansions would necessarily be no better than 12 in such a case. It should be borne in mind that those two experiments were tried with the same engine; and that the engine which had cylinders rightly proportioned for a 12-expansion trial was not rightly proportioned for a 20-expansion trial. For instance, in the trial G_4 , with 12 expansions, the range from mean admission to exhaust was less than 60° F., in each one of the four stages into which the expansion was divided. In the high-pressure cylinder it was only $57\cdot2^{\circ}$ F.; whereas, in the trial with 20 expansions, the range in the first cylinder was $83\cdot5^{\circ}$ F. Under those circumstances, of course, the 20-expansion trial had no chance at all; and there was little reason to doubt that if the engine were re-made and the cylinder proportioned for 20 expansions, a gain would be shown in working with that number rather than with twelve. It did not, however, follow that, although there might be a gain in I.H.P. there would be a gain per brake HP. The additional piston-ring friction due to the larger cylinders might more than nullify the gain. In fact it might be said that if automatic expansion was to do its very best the governor would have to alter the size of the cylinders, as well as the point of cut-off.

Mr. Cowper. Mr. E. A. COWPER did not think he should have spoken if it had not been for the fact that the steam-engine was such an old friend of his. The experiments and calculations related in the Paper were most elaborate, and greater in number than was necessary; for he feared it would be only some of the younger members who would be industrious enough to master them all. He confessed that he had not had the time to do so. In one respect he thought the Paper might have been improved by making it perfectly clear to the meanest capacity, what was the quantity of water that had to be evaporated to produce a net horse-power clear of all friction. He did not mean to say that one could not get at it by studying the Paper and making some calculation; but to do that, a person must thoroughly understand a steam-engine to begin with. He did not say that the test of pumping water need be resorted to (and with such a quick-working engine it would be ridiculous to ask it), but if the engine were tried like the engines at the Royal Agricultural Society's Exhibitions—viz., with a good brake, and also driving its own feed-pump, air-pump and circulating-pump, and having all the credit of any condensation in the steam-pipe, loss

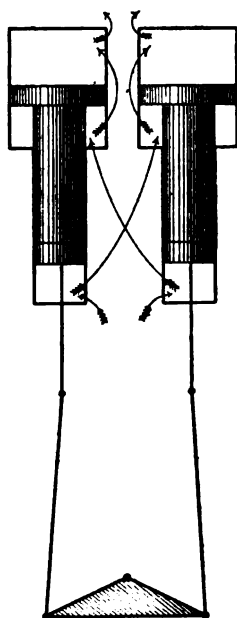
at the safety-valve, &c.,—one could compare it commercially with Mr. Cowper. numerous other trials of engines at once. But the experiments recorded in the Paper were directed distinctly to the behaviour of the steam under certain circumstances, one notably being the high speed of the engine. It was satisfactory to note that the "wire-drawing" of the steam was not great; that was owing to the passages being short and of large area, rendered possible by the central-valve arrangement. He understood that the engines had been proved again and again to develop power with great economy in driving dynamos direct at high velocity; and it would seem that they were well fitted for that kind of work, and for steam-launches and torpedo boats, as they ran very quickly and, owing to their being single-acting, kept one brass of the connecting-rod and of the plummer-blocks always in contact with the shaft. He would mention a point on which some disagreement existed. It was well known that he advocated the use of "steam-jackets," as he thought, with reason; for he had proved their value during more than forty years, and could not have made his "compound engine" without them. But in the present case it was argued that the condensation of steam in the cylinder, and its re-evaporation therein, was limited by time; and that at 400 revolutions or cylinder-fuls of steam in a minute, the percentage on the whole power could not be great. It was, however, admitted that steam-jackets might be of some use, though it must be borne in mind that their first cost was an item for consideration.

Mr. HENRY DAVEY considered that the chief value of the Paper Mr. Davey. would be found in the tabulated comparative results of a series of experiments under different conditions of working. It possessed a peculiar charm in the perfect way in which theory had been brought to the aid of practical investigation. Pure theory was often misleading in the absence of practical knowledge to guide its application; but here was theory brought powerfully to the aid of practice. It should not be lost sight of that the experiments, although representing the economic value of different modes of working the Willans engine, were more or less special experiments. It was necessary that the trials should be free from variable losses which would vitiate the results. Care was taken to avoid errors due to the circumstances and imperfections of every-day work. The same might also be said of many other carefully conducted engine-trials, made to ascertain the economy of an engine of any particular make. More uniform and accurate results were obtained by measuring the water from the condenser, than by measuring the feed into the boiler. For it must be noticed that the

Mr. Davey. experiments were directed to engine losses, and should not be mixed up with steam-pipe and boiler losses. That was recognized years ago by Messrs. Farey and Donkin; but since that time surface-condensing had become more general, and from the surface-condenser the condensed steam could be actually weighed; whereas, by the Farey and Donkin system, it was a matter of calculation from observed temperatures, and therefore it was not so certain in its results. In carefully conducted engine-trials with large engines, he thought it would be found that the difference between the measurement of the water entering the boiler, and the water coming out of the condenser would fall within 5 per cent.; although a greater difference would probably occur in every-day work. It should be observed that the engine did not drive its air-pump, but, as the results were all given in terms of I.H.P., that did not matter. It would have been useful to have had a record of the actual work done by the engine to compare with the indicated power. In former times engineers took the duty of the boiler and engine together, and expressed it in lbs. of coal of known quality per I.H.P., or, with pumping-engines, in units of work per cwt. of coal. The method was imperfect, because it did not make it appear whether the duty of the engine was good or bad, because of a good or bad boiler or engine, or because they were both good or bad; but the record for practical and commercial purposes was a useful one. Now with the aid of independent engine- and boiler-trials, and with sufficient reliable data, the best class of engine, and also the most suitable boiler could be selected; but the cost of the working establishment could not be neglected, and that, for various reasons, differed with all engines from calculations merely based on the results of engine- and boiler-trials. Turning to the Paper, he found that the Author had adopted in his engine the Cornish cycle. Mr. Davey had, in that room, spoken on the economical value of that cycle, not from a theoretical point of view, but because he had found from prolonged practical experience and observation that the Cornish engine did a very much higher duty for a given pressure of steam and a given range of expansion than any other engine he knew of, and he thought the Author was right in applying the Cornish cycle to his engine. It had been stated that, for pressures up to 150 lbs. per square inch, the compound engine with the Cornish cycle was likely to prove superior to the triple engine. He had long been under the impression that that would be so, and had made compound engines with the Cornish cycle, of the design illustrated in *Fig. 49*. In the Willans engine he observed

that the Cornish cycle was employed in all three cylinders. There Mr. Davey. was a receiver between each, and one between the low-pressure cylinder and the condenser. Under such circumstances, he would anticipate considerable advantage from steam-jackets, especially for the bottoms of the receivers, which formed covers for the cylinders below them. If water lodged anywhere, it would do so in the bottoms of the receivers. There need be no jacket on the last receiver. The necessity for steam-jackets was apparent from the fact that in all the results there appeared to be a large percentage of water in the steam at all stages of expansion up to the low-pressure release. The graphic methods used by the Author were valuable and instructive, especially the straight-line diagrams; which did not, like some of the others, relate to an ideal engine, but to the actual engine experimented on. The percentage of water in the steam was high in all the trials. Comparing C_4 with D_4 in the triple series, it would be seen that with steam at 55 lbs. per square inch and 14 expansions, there was 32 per cent. of water at low-pressure release, and with steam at 130 lbs. per square inch and 14 expansions, there was 26 per cent. of water. With the greater range of temperature there was less condensation, the thermal efficiencies being the same in both cases; whilst there was only one-seventh less feed-water used per I.H.P. as the result of increasing the initial pressure from 55 lbs. to 130 lbs. per square inch, the expansions in both cases being the same. In the compound series (E_3) with steam at 130 lbs. per square inch and 11 expansions, the feed-water was 15·18 lbs. per I.H.P., against 13·39 lbs. in the case of the triple (D_4) with 130 lbs. per square inch initial pressure and 14 expansions. It was reasonable to suppose that the mechanical efficiency of the compound would be somewhat higher than that of the triple engine, and that the small saving in feed-water might be scarcely worth the cost of obtaining it. As to the most useful ratio of expansion for a given initial pressure, it would be seen that *Fig. 7* showed 6·5 expansions as the limit for 50 lbs. pressure per square inch; but the experiments (C_4)

Fig. 49.



Mr. Davey. showed that with steam at 55 lbs. per square inch and 14 expansions, the feed per I.H.P. was 15.41 lbs., and (L_2) showed that with steam at 60 lbs. per square inch and 6 expansions, the feed-water was 18 lbs. per I.H.P. That indicated that the limit of useful expansion was higher than that shown on the diagram, but it was conflicting to find in experiment (L_3) that with steam at 60 lbs. per square inch and 11 expansions, the feed-water per I.H.P. was 18.25 lbs. Assuming the results to be correct, the only apparent reason for the great economy of the 14 expansions over the 6 and the 11 expansions, was afforded by the fact that in the first case the engine was worked triple, whilst in the other cases it was compound. In regard to the use of automatic variable expansion-gears, he was glad the Author had given consideration to them, and had made experiments in that direction. With steam-engines fashion exercised great influence. At one time there was such a rage for a true horizontal line on the indicator diagram up to the point of cut-off, that it was considered to be of most vital importance; and it was the only part of the diagram that some people could appreciate. The value of automatic expansion had been greatly over-rated, and in numerous instances complicated gears had been used where a simple throttle would have been just as effective. Referring again to the Tables, it would be seen that what was called "plant efficiency" was expressed by the ratio which the theoretical mean pressure bore to the mean pressure without clearance; and not, as he thought it should be, to the real mean pressure of the diagrams. As the efficiency was calculated by the Author, it led in one case to an anomalous result of 102 per cent. He did not think that "plant efficiency" was quite the proper term to use. "Plant efficiency" sounded as if it meant the actual compared with the calculated, which it did not mean in that case. In the Tables thermal efficiency was expressed in terms of available energy, and almost the highest thermal efficiency was obtained with steam at 55 lbs. per square inch expanded 14 times—producing of course a very low mean pressure, only 10.8 lbs. The consumption of steam was 15.4 lbs. per I.H.P. against 13.4 lbs. with 130 lbs. per square inch initial pressure, 25 lbs. per square inch mean pressure and a lower thermal efficiency. He did not point out this because of its wanting explanation, but to make it clear that the various efficiencies did not run in parallel lines, and that a high thermal efficiency might be coupled with a low real efficiency.

Dr. Hopkinson. Dr. JOHN HOPKINSON observed that it might be useful to point out how the terms in a formula used in the Paper arose. Consider

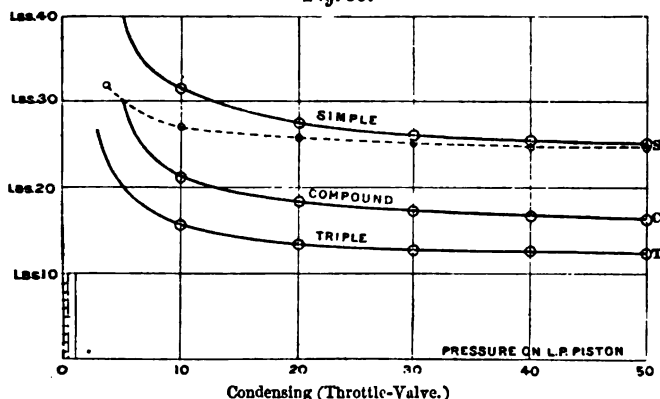
an indicator diagram of an engine, without the extension due Dr. Hopkinson. to the release being at a lower temperature than the steam had attained at the completion of the expansion. Heat was absorbed at constant temperature during the time at which the pressure was constant; there was next adiabatic expansion, then rejection of heat at a lower temperature, and a gradual increase of heat and a rise of temperature. The heat was absorbed at the maximum temperature, and was rejected again at the lower temperature. But heat was also absorbed as the water was heated from the lower to the higher temperature. Instead of the normal diagram, it might be supposed that the steam was condensed to such a point that, on compressing it further adiabatically, the diagram might be brought back to the point from which it started; that is to say, the steam would be reduced to water at the boiler-temperature and pressure. If that were so, the duty of the steam would be the first term in the formula $(1,438 - 0.7) \frac{T_1 - T_0}{T_1}$; but, in addition to that, there was, in fact, the heat absorbed during the gradual heating of the water, from the lower temperature to the higher, before it was converted into steam. The work to be obtained from this heat was expressed by the other terms of the formula, viz., $(T_1 - T_0) - T_0 \log. \frac{T_1}{T_0}$; so that the first portion of the formula was due to the heat absorbed at the upper temperature alone, and the other portion of the formula was due to the heat absorbed in heating water from the lower temperature to the higher. There were one or two other points to which he desired to refer, particularly with regard to the use of the steam-jacket. The Author had stated that steam-jacketing was useful in all cases, but it was much less useful when the reciprocations were many than when they were few. He thought that position was incontrovertible. No one, he thought, would doubt the enormous use of steam-jacketing when the reciprocations were few, and when the surface of the cylinder would be cooled to the full extent due to the expansion of the steam. On the other hand, if the reciprocations were many, the condensation and evaporation would be less affected by heating the outside of the cylinder. There would not be time for the heat to be conducted through the cylinder to the outside, or from the heated exterior to the interior of the cylinder. Therefore, when the rate of reciprocation was high enough, the advantage of steam-jacketing was materially reduced. That, of course, did not affect the position taken by Mr. Cowper,—that the advantage of steam-

Dr. Hopkinson. jacketing when the reciprocations were few, and the cooling would be complete, was very great indeed. With reference to the advantage of increased expansion in producing increasing efficiency, he gathered from what Mr. Davey had said, that he viewed it as a question of indicated horse-power. It was abundantly clear that increased expansion would give, with regard to indicated horse-power, increased efficiency; for it simply meant that, having expanded the steam to a certain extent, by expanding that same steam further increased work could be got from it; and, if that were done, clearly there must be increased efficiency. But, if he understood the matter, the Author had considered that, when steam was expanded beyond a certain point, it was necessary to increase the size of the engine, and, therefore, to increase the frictional losses in it; and when a certain point was exceeded, the increase of those frictional losses became greater than the increased amount of power which the indicator diagram showed.

Mr. Rigg. Mr. ARTHUR RIGG was inclined to think that the experiments described in the Paper would show that the ideas referred to by Mr. Davey as to expansion, and the rates of expansion, would require modification before they could be entirely received. One point to be remembered was,—scientific experiments of that character ought not to be accepted as applicable to all engines. Indeed, he did not think that the Author would have claimed for them general application. They were, however, valuable as applied to this particular engine; and it was a curious thing that the result of all such experiments as these tended to make engines simpler and simpler. With regard to the Author's straight-line diagram, the scheme was an admirable one; and many engineers had used it for various purposes. If, for example, they wanted to make a table of prices—say of engines—they put the HP. along a horizontal line, and the prices on a vertical scale, fixing two or three prices at different positions, and drawing a straight line between the points so calculated. Then, to find the proper cost of intermediate or larger or smaller sizes, it was only necessary to measure the height of vertical lines to their intersection with the oblique line. Of course, in applying a straight-line diagram to prices, the same class of engine would have to be taken throughout, or the result would be incorrect. The Author's returns had been made by an engine where the rate of expansion had been fixed, and the average pressure had been produced by the action of a throttle-valve. *Fig. 50* was reproduced from the Author's diagrams. It gave the weight of steam used per I.H.P. per hour with a

simple engine on the top line, with a compound engine on the second line, and a triple-expansion engine on the third line. It would be observed that, from 50 lbs. per square inch, the quantity of water slightly increased, and then increased with greater rapidity as the rate of expansion advanced. There was another line where super-heating took place, as shown by a dotted curve underneath the simple engine diagram in the *Fig.* This dotted curve exhibited the gain effected by slightly wire-drawing, and thereby drying the steam. It was interesting to see what effect a diagram of that character would have, by comparing it with that of another engine. There was only one engine that he knew of, with regard to which returns were available for such a diagram—namely, the Westinghouse engine. Those returns had been plotted on two diagrams, one at 80 lbs. per square inch and the other at 120 lbs., *Figs. 51 and*

Fig. 50.

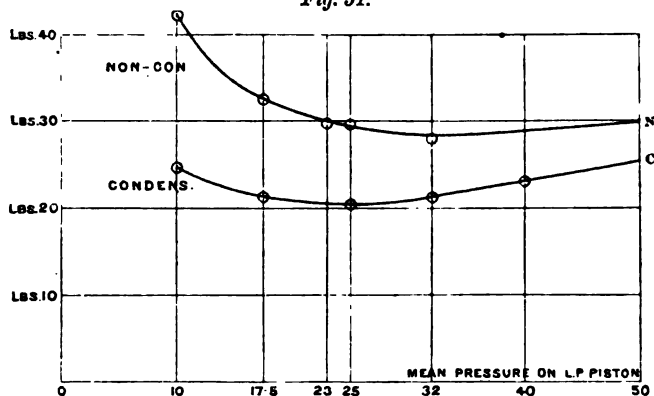


WILLANS ENGINE.—POUNDS OF WATER PER I.H.P.-HOUR.

52. Beginning from the right-hand side, it would be observed how the line curved down, indicating that the rate of water-consumption decreased as the rate of expansion increased; and showing the difference which the Author had shown on *Fig. 38, Plate 2*, comparing the effects of varying rates of expansion and the action of the throttle-valve. It also showed that there was not much good in all the mechanism required to vary the rate of expansion. The dots shown on the lines were wonderfully close, and a curve had been drawn through them, making slight corrections. The experiments with the Westinghouse engines had been conducted with remarkable accuracy. The difference between the sizes of these engines was a point to be noticed. The Westinghouse engines

Mr. Rigg. included engines from 200 HP. to 40 HP. There was not much difference in the piston-speeds, the Willans being 200 feet and the Westinghouse 290 feet per minute. But the law governing the effects of variable expansion and the use of throttle-valves held good, however large the engine. The Westinghouse engine alluded

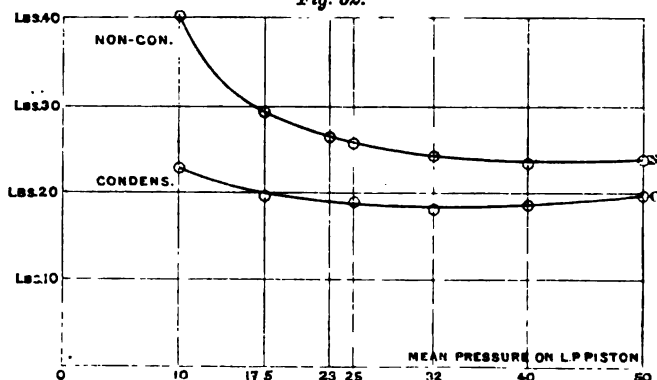
Fig. 51.



Compound.—Variable expansion.—80 lbs. pressure.

WESTINGHOUSE ENGINE.—POUNDS OF WATER PER BRAKE-HP.-HOUR.

Fig. 52.



Compound.—Variable expansion.—120 lbs. pressure.

WESTINGHOUSE ENGINE.—POUNDS OF WATER PER BRAKE-HP.-HOUR.

to had 14-inch and 24-inch cylinders, the stroke being 14 inches for both. The cranks were opposite, and the pistons were practically balanced. The next point to which he wished to refer was the importance of avoiding wet steam. Most engines in the

country were fed with wet steam. Nothing could be more Mr. Rigg. pernicious. According to the practice of engineers at the present day, or of the architects who made designs for mills, the engine was generally put in a low situation, so that the water from the steam in the boiler, and that which collected in the pipes, got into the engine and had to be discharged. The old engineers knew better, and when they put in a beam-engine they set the engine high, so that waste or condensed water might run down towards the boiler. That had the effect of clearing the cylinders of the water. In the case of one of Mr. Rigg's high-speed engines, at the Crystal Palace, at the Mining Exhibition in 1890, all the steam-pipes were underground—there were some traps that were supposed to carry off the water, but they did not do so. When about a dozen engines were running, the water got away fairly well; but directly the engines stopped, about 8 o'clock, when the electric light required to be worked, all the water had to go through this high-speed engine, and adversely affected its efficiency. Steam- or hydraulic-engines could be made to run at 500 revolutions per minute, but he defied any man to get an engine to work at that speed by water and steam mixed.

WESTINGHOUSE ENGINE—WATER RATES PER BRAKE HORSE-POWER.

1	2	3	4	5	6
Brake H.P.	Average Pressure. Lbs. per Square Inch.	Boiler-Pressure, Lbs. per Square Inch.			
		120	100	80	60

CONDENSING.

		Lbs.	Lbs.	Lbs.	Lbs.
200	50.0	19.62	22.53	..	..
160	40.0	18.86	20.02	23.17	..
130	32.0	18.38	19.56	21.32	24.30
100	25.0	19.14	19.44	20.34	20.10
70	17.5	19.80	20.05	21.43	22.57
40	10.0	22.90	23.12	24.75	22.55

NON-CONDENSING.

200	50.0	23.94	..	..	..
160	40.0	23.50	25.20	..	..
130	32.0	24.32	26.42	27.70	..
100	25.0	25.57	27.75	29.80	..
90	23.0	26.51	28.30	29.80	31.70
70	17.5	29.40	30.77	32.48	36.00
40	10.0	40.05	39.30	42.75	45.82

Mr. Beaumont. Mr. W. WORBY BEAUMONT desired to refer, in the first place, to the measurement of the pressure and the temperature of the steam, which had been taken in the experiments as that of the steam-chest, and not that of the mean temperature of admission. Judging from a remark in the Paper, that would not appear to have made much difference; but it certainly seemed that it must be much more nearly correct to take the temperature of the steam as it was delivered to the engine, rather than to take the temperature after it had partly gone through the engine. With regard to the efficiency obtained as the result of the experiments under consideration, in comparison with that obtained from the trials of the non-condensing engine, the condensing-engine was said to have an efficiency of 63 per cent., while the non-condensing engine had an efficiency of 78 per cent. That meant that the condensing-engine had not made quite as good a use of what had been given to it as the high-pressure or non-condensing engine; but for all that, it was, of course, to be understood that in almost all cases, the advantage was greatly on the side of the non-condensing engine. It appeared to him clear that some further term was wanted with regard to efficiency; because the statement that the non-condensing had a higher efficiency than the condensing-engine might be misunderstood—in fact, something of the nature of what might be called commercial efficiency, taking into consideration the actual cost of I.H.P. in steam, rather than simply the relation between the heat-units ideally utilized in one engine and in the other. He supposed every one agreed as to the value of the $\theta \phi$ diagram with which the Author had worked; but he did not think that all would agree with Mr. Robinson's apologetic statement with regard to what he had termed the ordinary limits which had been assumed. One of the good things done by the Author was to show that it was absurd to talk about the efficiency of the real steam-engine with reference to a thing that was, and could only be, a purely ideal engine. Mr. Robinson took a limit for the non-condensing engine, say, 120° F., as the lowest temperature to which it was desirable to go. He had taken an arbitrary limit, but everything in connection with the steam-engine became arbitrary at one point or another; and it was much better that it should be understood that the figures related to what one might call a possible engine rather than to an ideal engine. It would be interesting to know by brake-experiments where the limit was reached at which triple-expansion advantages were lost in the disadvantages connected with that form of engine. In the North of England, among the builders of the large engines used for

driving cotton-mills, the opinion was generally held that the compound engine had arrived at as high a state of efficiency as could be obtained with any greater number of divisions of the expansion range; and that the possible gain by adopting further cylinders, valve-gear and other things, might be more than lost in the friction, maintenance and interest upon greater first cost. He thought that higher pressures than those now used would be productive of greater efficiency and economy; and possibly it might be necessary to use three or four stages of expansion in order to secure those advantages. Valuable as the Paper was, its value would be greatly increased by brake experiments, or experiments giving electrical output. He would ask whether any note was made of the power that was taken to work the air-pump? It was shown on the diagram, *Fig. 8*, as though it were worked by a belt from shafting. For comparison with some other engine-results, it was desirable to know whether or not the engine was to be debited with the power taken to work that pump.

With reference to a remark that had been made respecting the Cornish engine, it might be perfectly true that few people realized the cause of its great economy; but it had been pointed out as long ago as 1865. He would like to quote a few lines showing that it was thoroughly understood at that time, and perhaps earlier.

“A remarkable instance of the advantages following on the suppression of the cooling influence of the condenser is afforded in the economy of the Cornish pumping-engine. In this form of steam-machinery, a portion of the cylinder, the lid and one face of the piston, must always remain unaffected by the condenser; because, at the termination of the in-door stroke, only the equilibrium-valve is opened, and, while the piston is going out, a pressure equal to that present at the end of the stroke is kept up in the cylinder; evaporation is therefore arrested and the temperature is fully maintained. Before the exhaust opens, the equilibrium-valve is closed, so that no direct communication ever exists between the steam-side of the piston and the condenser. The entering steam has in consequence only to raise the temperature from that due to the terminal to that due to the initial pressure.”¹

That would be especially interesting if taken in connection with other things stated in the same Journal, with regard to condenser-effects. The only other point to which he wished to refer, was the statement made by Mr. Robinson at the commencement of the discussion, to the effect that attention should be paid to what was being done on the Continent, and that the great scientific advances

¹ *The Engineer*, vol. xix. p. 163.

Mr. Beaumont. there made should be estimated at their proper value. The suggestion implied seemed to be that English engine-builders ought to go to school on the Continent, and that if they lost their trade, it would be because they had not learnt all they might learn there in regard to the application of certain scientific investigations. No doubt it was sometimes necessary to eat humble pie, and recognize that there were certain reasons for estimating at a high value a great deal of what was taught on the Continent. He believed, however, that the Author had left matter to occupy the minds of Continental engineers for a long time. They would find enough in the Paper to exercise their analytical studies for many years to come, and to show them that English people, if they had not done so much in study of the work of others, might still be at the head in practical research and its application. He believed it was true that a Continental firm had taken a licence from Messrs. Willans and Robinson to make English high-speed engines. It could be safely maintained that, vast as was the value of a great deal of the quiet study prosecuted on the other side of the Channel, English engineers might still hope to maintain their position as leaders in those great branches that had kept them in the first rank amongst engine-builders, locomotive-builders, and marine engineers. For the production of rank and file, the Continental system was excellent; but English methods produced men, who, like the Author, were originators of practice, theories and industries.

Mr. Gray. Mr. J. MACFARLANE GRAY added to the formula written by Dr. John Hopkinson, the equivalents of the three terms in the letters used in *Fig. 3*, thus:—

$$L + (K + M) - M = L + K,$$

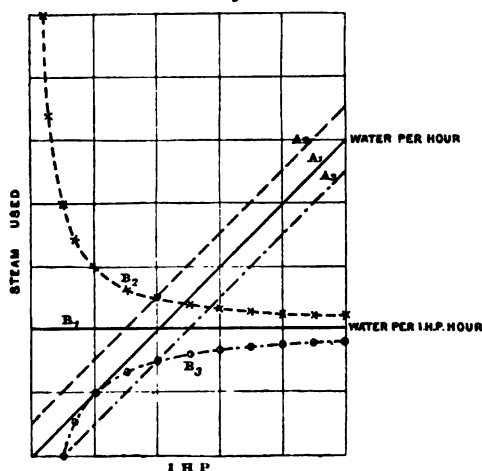
so that the $p v$ diagram might be also read on the $\theta \phi$ diagram, to which the mathematical expressions in the formula directly related. The memory of the Author, and the fact that he had the honour of his friendship, would always be an agreeable recollection. Of course, the peculiar representation of the thermo-dynamic features of the engine were partly due to the Author's association with him. Their connection was accidental, but by this means the subject had been more rapidly brought into public notice than it otherwise would have been. He desired to say a few words on the meaning of "plant efficiency." Working with dry saturated steam in an adiabatic engine, for which the admission-pressure, the terminal-pressure, and the final back-pressure were all specified, and for which the

feed was of the temperature of the exhaust, there was a certain Mr. Gray. calculable duty, the realization of which would be perfection; and this would be a reasonable standard of comparison for the performance of any engine. The percentage of that duty actually obtained was what he would call engine-efficiency. Line 28, Table III, Appendix III (not here reproduced), gave that ratio, but in the standard the steam apparent at high cut-off was employed. Reducing the numbers in line 28 by the percentage of missing steam given in line 50, the resulting engine-efficiency came out 70·3, 70·37, 68·5, 61·6, 63·2, 69·24, 64·1. The thermal efficiency, line 35, was based upon the actual steam used; but it ignored the terminal pressure, and included in the standard of comparison the excluded toe of the diagram, which would be a miracle in the work output. The numbers given, properly understood were, however, also significant. He urged the adoption of the 70·3, 70·37, &c., as engine-efficiency, instead of 56·84, 57·41 as thermal efficiency. In the Author's opinion, however, that course would have been read as making the result appear better, and he preferred to sacrifice some advantage, rather than be thought to be studying effect in the choice of methods of representation. The name "plant-efficiency," was not sufficiently explanatory. Given an engine for which the cut-off, the ratio of expansion, and the final back-pressure were fixed, there was theoretically a certain calculable mean effective pressure for an adiabatic engine. The man who thought to buy such a plant might wish to know what portion of that pressure would be obtained in practice. That affected the torque only, not the economy. Line 28 referred to, answered the question in reference to that engine under certain varying conditions described. To obtain that result, it might be necessary to more than fill the admission-space with steam, for the initial condensation was not reckoned in the standard; although its re-evaporation counted in the result, in some cases, making the plant-efficiency apparently greater than that due to the steam according to its measurement.

Professor ALEX. B. W. KENNEDY proposed to show his sense of Prof. Kennedy. the value of the Paper by saying a few words arising out of a point which Mr. Willans had made peculiarly his own—the matter of the way in which steam-consumption represented itself graphically, which he was glad to hear Captain Sankey proposed to call the "Willans law." It was astonishing, if not even humiliating, to think how long this thing had been lying straight under one's eyes, and yet had not been seen. It had been customary to plot curves per I.H.P.-hour without taking the trouble to plot the

Prof. Kennedy. actually observed quantity—the weight of water used per hour. Thus many things had escaped notice that would have been otherwise revealed. He might first point out what this law of the Author's meant. If on one axis were taken any scale of power—I.H.P. or E.H.P.—and on the other a scale of steam used in a given time, the law showed that the curves co-ordinating the steam and the power would be straight lines. The straight line might lie in three different ways, as shown in *Fig. 53*. It might, first of all, lie so as to pass through the origin, as the line A_1 , which would mean that the engine used no steam at all when it was doing no work. It had been stated by Mr. Robinson that he proposed to find out by experiment how much steam an engine did use when it was doing no work; for that purpose he presumed he would open

Fig. 53.



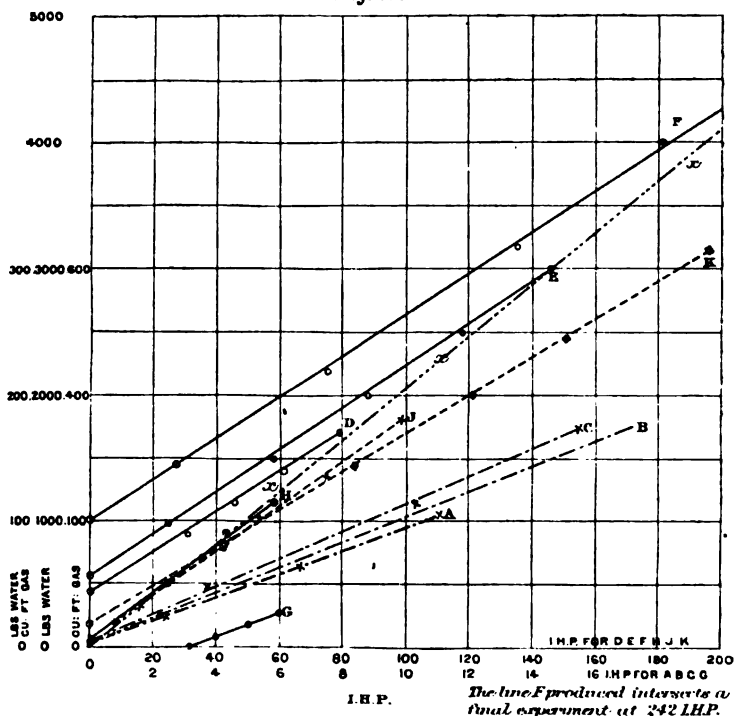
the stop-valve, shut the exhaust-valve, open the drains to a steam-trap, and drive the engine by a dynamo as a motor, simply letting the steam do just as it liked. No doubt this would show that the engine would use steam—mainly, of course, by condensation and radiation—although it did no work. In this case the diagram would cross the axis above the origin (as A_2), showing that the engine used a certain amount of steam when it was doing no work, and all the diagrams hitherto had been of that kind. Or, lastly, it might cross the axis to the right of the origin (as A_3), and he had been puzzling his brain to see what that would mean, and, in fact, put it down as absurd, until that morning Mr. Legros pointed out to him that it had a perfectly definite meaning; it

meant that the engine worked backwards thermodynamically. Prof. Kennedy. An engine might do work in refrigerating by continually taking the pressure off the surface of water which was to be cooled, and so evaporating it. The engine, that is, might convert the water into steam. The engine would be working the boiler instead of the boiler working the engine; and in this case, of course, power had to be expended before steam was obtained. The three lines, A_1 , A_2 and A_3 , *Fig. 53*, represented three different curves, if their results were plotted as water used per HP.-hour. These curves were shown in the lines B_1 , B_2 and B_3 , of which B_2 was the usual case. He wished, however, to draw particular attention, for certain reasons, to B_1 , which was a horizontal line. If the curve of total water per hour was a line passing through the origin (as A_1)—no steam being used at no power—then the steam used per HP.-hour was the same at all powers from zero upwards. It followed that, in any diagram of the nature of *Fig. 53*, any line whatever drawn (like A_1) through the origin corresponded at all points to an equal consumption of steam per HP.-hour,—a fact from which very interesting results would be found to follow.

He exhibited a few curves (*Figs. 54 to 57*), which showed how widely applicable the Willans law proved itself to be. *Fig. 54* was comparable with those given in the Paper, the base being on a scale of I.H.P. The lines A, B and C represented tests of three gas-engines. Here the working-fluid was one with which no losses occurred from initial condensation, and with which, therefore, the lines might be expected to pass very nearly through the origin; it would be noticed that they actually did so. This corresponded with the fact that, in a gas-engine, the consumption of gas per I.H.P. was much more uniform than was usually found in steam-engines, although the difference practically disappeared when the gas was measured per E.H.P. The three lines, D, E, F, represented three Willans engines of different sizes. They were all non-condensing. They were, he believed, not strictly comparable, because they had not all exactly the same expansion, but they were nearly so. This matter of the comparison of different-sized engines was not mentioned in the Paper, but was of great importance, and the use of the Willans diagram threw much light upon it. It would be noticed that any line through the origin, such as x , cut the three curves in three different points. Any such line, however, represented the same consumption of steam per I.H.P.-hour, as he had just pointed out. In this case, it was apparent that each of the three engines, at nearly its own full power, was using the same amount of steam per HP.-hour;

Prof. Kennedy, and that therefore it was, so far, most economical to use the smallest possible engine. The three lines H, J, K showed the results of three Willans engines of different powers worked condensing. The most obvious point was that they all passed very much more nearly through the origin than the former lines. This had surprised him somewhat at first, but after all it was merely a matter of common sense. If a condensing-engine were used it might be expected to use less steam per HP.-hour at all

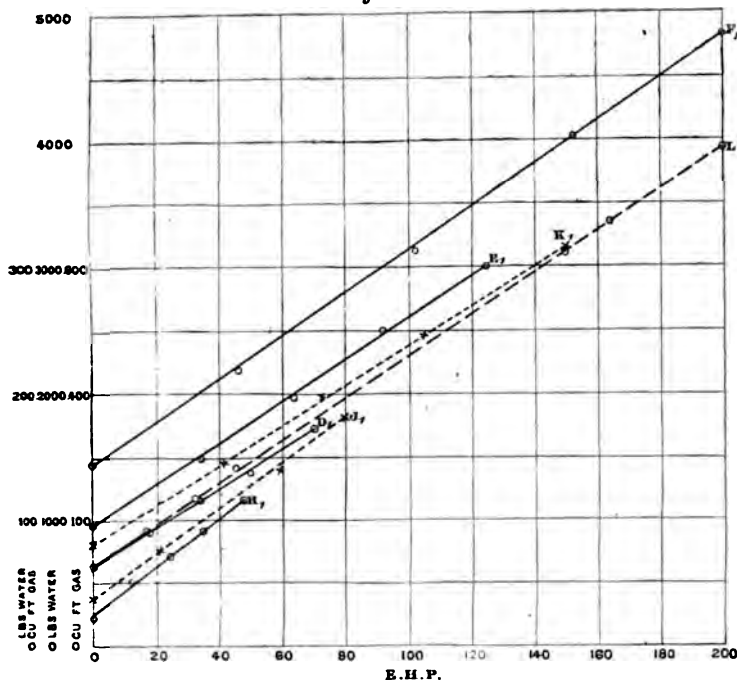
Fig. 54.



powers than a non-condensing engine. But if the Willans law was true, the amount used per hour should still be represented by a straight line. There was no reason why the slope of this line should be very different from that of the former. It was therefore obvious that what was to be expected was simply a bodily shifting of the line downwards, and this was exactly what occurred. The initial waste, therefore, was bound to come very much less. A second point brought out by the diagram, and

by no means an obvious one, was that the lines were no longer Prof. Kennedy. even approximately parallel, but the larger engines had water-lines sloping at a smaller angle. The larger-sized engines of this type, used with condensation, were decidedly more economical than the smaller-sized ones. It would be noticed that all three sizes used nearly the same amount of water per hour between 30 I.H.P. and 50 I.H.P.; and that, above this, each size of engine was more economical than the next smaller size. He had no similar experiments with Messrs. Willans and Robinson's new

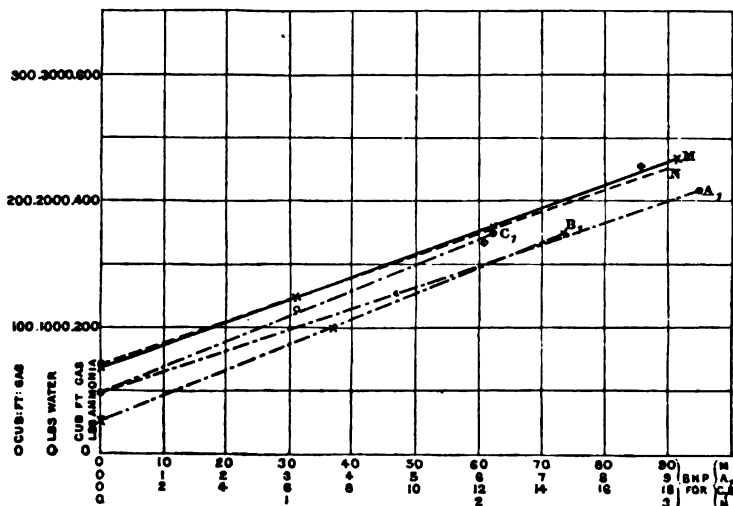
Fig. 55.



type of condensing-engines (those whose proportions were based on the results given in the Paper under discussion); and he was therefore unable to say into which category they would place themselves. Possibly Captain Sankey could say something on this point. The line G (*Fig. 54*) was obtained from experiments on a refrigerating-engine working exactly in the manner he had mentioned. It was given in the figure more as a curiosity than for any other reason. Instead of plotting out the results on the basis of the I.H.P., it was as easy to draw them on the basis of

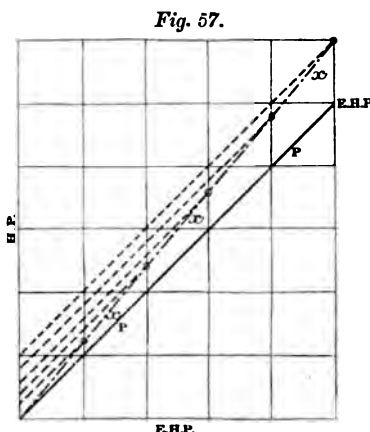
Prof. Kennedy. E.H.P. or B.H.P. *Figs. 55 and 56* showed some of his former results plotted in this way. The results from the same engines were given in similarly lettered lines in the different figures. D_1 , E_1 , and F_1 were three non-condensing Willans engines, and H_1 , J_1 , K_1 , were three condensing Willans engines. As to these last, it was only fair to say again that none were of the latest type of condensing-engine made by the firm, and discussed in the Paper—these latter having given considerably better results. L was a line taken from tests of the Parsons turbo-motor, which lay most extraordinarily within the general limits, and the observed points of which lay most closely in a straight line, although it was, of course, a motor of an entirely different type from that of an ordinary steam-engine.

Fig. 56.



In *Fig. 56* the base of the diagram was brake-HP. The lines A_1 , B_1 and C_1 represented again the three gas-engines of *Fig. 54*. It was obvious that, neither with these nor any of the other machines could the lines pass so nearly through the origin as in *Fig. 53*; for in all cases the zero of brake HP. was accompanied by some considerable I.H.P.—the power, namely, which was necessary to drive the engine itself at full speed, running light. Line M belonged to an ordinary horizontal Corliss engine, and line N to a small motor driven by anhydrous ammonia, but in the last-named case the points were indifferent. It was a remarkable thing that Willans' law appeared to apply equally

well to machines so extremely different from his own engine. He Prof. Kennedy, wished to refer briefly to *Fig. 57*, as it represented, he thought, a direct extension of the use of the instrument which the Author had placed within reach when he gave this law. Taking a base, not of indicated, but of useful HP., and taking the same scale for power (not now for water) on the vertical axis, a line at an angle of 45° as P.P., might represent useful HP. Above that was plotted a line representing the corresponding I.H.P., and this line he had found to be almost always a straight line. Any vertical line would cut the two oblique lines, the one in the useful HP., and the other in the corresponding I.H.P., and the distance between the two would be the I.H.P. for the engine—the amount of power taken to drive the engine itself. Very often the two power lines were sensibly parallel. In an average of thirty or forty Willans-engine tests, the power taken to drive the engine at full power was about fifteen per cent. more than the power taken to drive it empty. Whether that was a true average or not for other types of engine he did not know, but in ordinary engines he had often found the difference to be much greater; he gave the figure, however, for what it was worth. It was clear that with a type of engine which was as economical in small as in large sizes it was always most economical to use the smallest possible.



He was not speaking of economy in wages, but simply of the one point of economy in steam. In fact the Author's dictum was absolutely justified, that all engines ought to be worked as hard as possible, and boilers as lightly as possible. In *Fig. 57* he had drawn representative curves for four engines, each one larger than the one before it, and had assumed in each case that the power necessary to drive the engine was constant, and was equal to 10 per cent. of the maximum power of the engine. He had further assumed that the small engines were as economical as the large ones. He had then drawn the line *xx* passing through the origin, simply to indicate how in such engines the consumption of steam per I.H.P.-hour at the full power was absolutely the same in each case. The same line would show how much was

Prof. Kennedy. wasted if engines too big for their work were used. Of course where the larger engines had curves not parallel to the smaller ones, but having a less slope, the case would be altered, as he had pointed out in connection with *Fig. 54*. But that would simply mean that the engine was of a type in which the smaller were less economical than the larger sizes. That might be so in many cases, but in the case of Willans engines it was only so to a limited extent. There was an extraordinary resemblance between the results obtained in very large and in very small engines. There was a point raised in the Paper as to whether the steam ought to be measured going into or out of an engine. He had had doubts about it for a long time, but the Author's experiments had led him to believe that the most accurate result was to be obtained by measuring it passing out of the engine. Of course it was often impossible so to measure it, but wherever it could be done it was the best course to follow, where pains could be taken to get as accurate results as those obtained by the Author. It might be interesting for members to know how far results in practice bore out the figures given in the trials of Willans engines. He had frequently, during eight, nine or ten consecutive hours of ordinary work in an electric-lighting station, measured all the water, and noted all the power, and the points on the curve at which the work of each engine was done; and had then compared the water actually used with that which ought to have been used; and he had found that it came within about 5 per cent. — a difference not more than might be expected from the feed-pumps and the general waste. For results over a whole week, where the nights came in, and when also the starting and stopping was included, it was not within 5 per cent., but was more like 10 per cent., and often considerably more. There were losses between the boiler and the engine due to the leakage of valves, to open drains, to condensation in pipes, and to several other causes which he feared had not yet been explained. Taken altogether those losses were considerable and gave a good deal of trouble.

Mr. Crompton. Mr. R. E. CROMPTON felt that a few words on the subject of the trustworthy nature of the results which could be obtained from the trials described, might add to the value of the Paper. It was well known that electrical engineers who were designers of central-station plant had to consider the fact that the proportion borne by the cost of the power employed by them to the total cost was much larger than in any other manufacturing process, except, perhaps, the driving of ships at sea. For that purpose they had to devote much attention to questions of economy connected with

the production of power. It was well known that he, for one, Mr. Crompton. had pinned his faith to a great extent in past years to the Willans engine; and he felt that he was justified in that course by the excellent and concordant results that he had obtained. Moreover Prof. Kennedy, who was unsurpassed in the care with which he made tests, had also obtained corroborative testimony to that effect. The point to which he wished to direct attention was that there were peculiarities of construction in the Willans engine which made it peculiarly a steam-meter, and a far more absolute measure of the steam passing through it than any other engine with which he was acquainted. This fact had been of enormous use to him in locating the losses that existed between the consumption of coal and the development of power. Over and over again it had been found that the monthly fuel-account did not agree with what it should be, when calculated from the estimated value of the boilers and engines as power-producers; but in every case, after due allowance had been made for ascertained losses, the Willans engine had been cleared from blame, and had given results varying not more than $2\frac{1}{2}$ per cent. from the results claimed for it by the makers when they sent it out. As Mr. Robinson and Captain Sankey knew, he had on several occasions written pointing out certain curious facts that appeared to require explanation; but in every case he had been eventually able to furnish his own explanation. In the works directed by him, which were in the Eastern Counties, coal was extremely dear—Welsh coal costing 24s., which forced them to use nothing but the most economical plant. The town was lighted by them, and as their own power required was considerable, they had organized a power-department supplying power for the public lighting and also for their own works. Each department was debited with the amount of power used. They had accurate means of checking by meters part of the power used, but up to the present they had not very accurate means of checking the power used on that part of the plant which was on the alternating system. For that reason it had been necessary to take complete sets of indicator diagrams at regular intervals of 15 minutes, for 24 hours consecutively. Every Wednesday for some months past he had conducted such trials, the results of which were at first disappointing. It came to this, that with three Willans engines of about 135 to 150 HP. they appeared to be actually using about 29 lbs. of steam per I.H.P., whereas they ought only to have used about 20 lbs. during hours when the engines were fully loaded, and 26 lbs. during hours of partial load; and it became necessary to find out where the balance was going. By separating the

Mr. Crompton. apparatus, the losses were located and the consumption of the engines had been found week after week to vary only between 20·8 and 21·5 lbs. of water when fully loaded, or within $2\frac{1}{2}$ per cent. of what they were supposed to use. This small variation might be due to errors in measurement. The effect of this had been to direct attention to losses which engineers ought to know of, but which all engineers did not appreciate at their full value, viz., losses in steam-pipes from condensation, losses in the pumps and other apparatus connected with the water-supply to the boilers. These were found to be greatly in excess of anything that would be believed, but which had now been accurately traced. The fact that when every loss had been debited to its proper source, the steam-consumption of the engines was shown to be 20·8 lbs. when fully loaded, and 24·8 lbs. when partially loaded, was enough to point his remarks. Some of his remarks on what all were beginning to call the Willans law had been anticipated by Prof. Kennedy, a law which he was proud to say was first promulgated at a discussion on a Paper read by himself. He would add his voice to those who would strongly wish that engineers should call it the Willans law; it was a law which, although possibly known before that date, was brought forward prominently by the Author for the first time.

Mr. Wingfield. Mr. C. H. WINGFIELD mentioned that among the objects of the Author's trials, one was of special interest to designers, viz., "To ascertain with a given steam-pressure and ratio of expansion the percentage of the theoretical mean pressure which is in this type of engine actually obtained in practice." This percentage, when known, would enable a designer (when the I.H.P. revolutions per minute, steam-pressure, number of expansions and back-pressure were given) to predict the actual mean effective pressure, and from it to determine the proper dimensions of a cylinder to develop the required power. Unfortunately, the back-pressure was a quantity which usually varied with the speed of engine, the boiler-pressure, and the expansion-ratio; and the "plant efficiency" was also variable. At 400 revolutions per minute, for instance, it varied in these trials with a compound engine, from 75·03 to 102·0. In calculating line 27, Appendix III, for the purpose of this comparison of actual with theoretical results, the Author had regarded the adiabatic as the ideal mode of expansion. That, no doubt, was more correct than the hyperbolic law; but as the mean-pressure was more easily calculated by the latter, he thought it would be preferred if results at least as consistent could be obtained by its use. It must be borne in mind that the

object under discussion was not, what law did the expansion-curve follow? but, what was the simplest way of estimating the probable mean effective pressure in a proposed engine?

It was frequently assumed that the actual mean effective pressure would be a fixed fraction of that obtained by deducting the expected back-pressure from the mean absolute pressure—the latter being estimated by multiplying the initial absolute pressure p_1 , by $\frac{1 + \text{hyp. log. } E}{E}$; and Tables had been published purporting to give the value of this fraction. This had been happily called by Professor Unwin the “diagram-factor” for different classes of engines.¹ This rule would be expressed algebraically thus—

$$m.e.p. = \left\{ p_1 \cdot \frac{1 + \text{hyp. log. } E}{E} - b \right\} \times \epsilon,$$

where $m.e.p.$ = actual mean effective pressure reduced to l.-p. piston (line 25 in Appendix).

p_1 = absolute pressure in the steam-chest (line 4 in Appendix).

E = nominal ratio of expansion as given under the reference letters in the Tables.

= $\frac{\text{volume of l.-p. cylinder}}{\text{volume of h.-p. cylinder} \times \text{cut-off in h.-p. cylinder}}$
 $\left. \begin{array}{l} b = \text{back-pressure} \\ \epsilon = \text{diagram-factor} \end{array} \right\} \text{ have to be estimated.}$

If more steam was passed through an engine by increasing the pressure or the number of revolutions, the back-pressure would usually rise, and the value of the diagram-factor, like the “plant efficiency” (line 28), would also be affected.

He had found, however, that if b , instead of representing the actual unknown absolute back-pressure, were made to stand for a quantity which he called a “virtual back-pressure,” found from trials of similar engines, this virtual back-pressure was not only independent of the revolutions and expansions; but the diagram-factor ϵ was less affected by the expansions, and scarcely at all by the revolutions.

On pages 7 and 8 of the Paper there were foot-notes, stating that the Author limited his standard back-pressure to 1.267 lb. per square inch, on the ground that a lower vacuum could only be obtained at a cost exceeding the gain. He thought it was Mr. Weir

¹ *The Practical Engineer*, June 17, 1892.

Mr. Wingfield. who just called his attention to this source of loss. Although an important point, he thought it had not been generally noticed. People were proud of a considerable vacuum in condensers; but he wished to point out that, under certain conditions, an improved vacuum did not give any increase of power, but only resulted in a waste of heat. The laws of the efflux of steam were not yet finally determined,¹ but Napier's experiments, as expressed in a formula adopted by Rankine,² were sufficiently accurate.³ These indicated that the weight of steam which would pass through an opening 1 square inch in area in 70 seconds was nearly equal to the absolute pressure of the steam; provided the absolute pressure on the side of the opening towards which the steam was flowing was less than about three-fifths of the absolute pressure on the high-pressure side. That meant that if there was a constant pressure of steam, and, therefore, a constant density, the velocity would be constant provided the vacuum was not more than three-fifths of the steam-pressure. If the indicator-card of an engine showed a certain back-pressure, and the condenser-pressure was three-fifths of that, or less, if the law was rigidly true the bottom of the diagram would not be lowered by further reducing the condenser-pressure, as there would be no increase in the velocity of the steam. The condenser would be cooler, because more heat would pass off in the circulating-water. Heat would also be wasted in providing power for the extra quantity of circulating-water; and all the heat wasted from the first of these two causes might have been left in the feed-water, and so have saved fuel. Although this was not strictly true, there was an undoubted tendency towards it. A good indicator-card might be got with 20 inches vacuum, and, perhaps, with 28 inches there was no further gain. Where this was so, it showed an improvement would result from larger ports. It was stated in the Paper that the Author was not aware whether it was generally known that much of the economy of the Cornish engine was due to the range of temperature being practically halved by the plan of letting the steam pass from one end to the other without further expansion before being exhausted. He thought there was possibly another reason for this device. He did not know what the original inventor had in his mind; but he had heard of a Cornish engine in which the

¹ "Experiments on the Efflux of Elastic Fluids," by Mr. George Wilson, *Engineering*, vol. xiii.

² *The Engineer*, vol. xxvii. p. 359.

³ An analysis of these experiments and of Rankine's formula by Mr. Macfarlane Gray is given in *Engineering*, vol. xiii.

difference of temperature at the two ends was so large, and the engine worked so slowly, that the piston became so big at one end of its stroke that it stuck fast at the other end. Of course the method of reducing the range of temperature would also prevent that trouble. It was said (page 20 of the Paper) that the diagrams from each cylinder had been measured collectively. If Mr. Robinson would explain how this was done, he was sure it would be of interest. On page 24, the short distance called *w* in the *Figs.* was defined as the water required by a frictionless engine doing no work at the revolutions specified. On page 25, radiation, conduction and cylinder-condensation were enumerated as the causes of this water-consumption, when the frictionless engine was developing no power. He thought there was another loss which had to be made up by part of this water mentioned previously by the Author,¹ the steam used in overcoming the back-pressure, pushing the atmosphere out of the way; in the present instance pushing the steam in the condenser out of the way. If the mean-pressure on the steam-side of the piston in a frictionless engine was not sufficient to balance the mean back-pressure, the engine would run backwards. The cylinder must, therefore, be filled at each stroke with sufficient steam to balance the back-pressure. The engine would not be moved by this steam, and no power would be indicated, the indicator-card being similar to that of *Fig. 25*. If the engine were started at say 400 revolutions per minute, being frictionless, it would not stop but would keep on measuring out cylinder-ful after cylinder-ful of steam at this pressure like a water-meter; and this amount of steam must be used at zero power, besides what was required to supply initial condensation, &c. There was an interesting point in *Figs. 27 to 30, Plate 2*, to which attention had not been drawn; but he thought the Author must have had it in mind. It would be seen on reference to these *Figs.*, that the lower of each pair of lines had been produced, and that they all intersected the base-line at the same point. Whenever, in a straight-line diagram of an engine or anything else, the lines converged to a point, it had always an important meaning. It was here a measure of the steam used to balance the back-pressure.

He was not sure, but he believed that the distance from this point to zero, measured along the base-line, would prove to be equal to the mean back-pressure. His reason for thinking so was that, as the lines produced were all indicated water, and they were all

¹ Minutes of Proceedings Inst. C.E., vol. cvi. p. 64.

Mr. Wingfield. straight lines, which represented the result of indicated work, where they were produced they would not suddenly change their character, but must still represent steam which was doing work ; and the only work in an unloaded frictionless engine was that of overcoming the back-pressure. As mentioned above, the back-pressure in the low-pressure cylinder was not given ; but it would be interesting to know if it corresponded with the distance from this point to zero. This could only be ascertained by reference to cards which were not given in the Paper. The upper lines in Figs. 27 to 30 also converged towards a point which, however, was a little above the base-line. There could be no doubt that this, too, had a definite meaning ; which, however, he had been unable to decipher. It would, he felt sure, repay careful examination. The steam at high-pressure cut-off should be the same per revolution, or nearly so, at all speeds, if the mean effective pressure reduced to low-pressure was also the same. Applying this as a check to Figs. 27 and 29, and dividing the height at which the lower line for 400 revolutions per minute intersected the vertical over 50 lbs. pressure per square inch into four equal parts, it would be found that the lines for indicated water at 200 revolutions and at 300 revolutions per minute passed almost exactly through the points so found. If moved so as to pass exactly through them, the lines would still pass fairly through the other points, with the exception of the highest point in the 300 revolutions per minute line of Fig. 27. Perhaps this would be a guide in selecting the right direction for these lines in future diagrams of a similar nature. It was encouraging to see (Fig. 29), that the initial condensation was only increased by increased pressure under conditions where it was least important. In the description of Fig. 38, the curved line was described as obtained by joining the points indicating 170 lbs. on the three straight lines in Fig. 36. This, he thought, only referred to the upper part of the curved line. To obtain the lower part in this way, many other lines similar to those in Fig. 36, but at 40, 50, or more expansions, would be required. The curve cut each straight line at two places, at only one of which the straight and the curved line had the same pressure, and therefore the same rate of expansion. The pressures at the other intersection were different (in Fig. 38 it was 65·85 lbs. per square inch for the straight line, and 170 lbs. for the curve), the same mean effective pressure being obtained for each by varying the rate of expansion.

Mr. Cowper. Mr. CHARLES E. COWPER confined his remarks to the connection between the formula for the work in heat-units due from 1 lb. of

steam, and the value of the same in *Fig. 2*; also applying the Mr. Cowper. numerical values to the $\theta \phi$ diagram, *Fig. 3*. For convenience of comparison, he would take 110° F. (as the Author had done on p. 7) as the lower or condenser temperature, and 310° as the higher or steam-chest temperature; or, on the absolute scale, 571° and 771° —a range of 200° . Applying these figures to the formula on p. 8, he obtained the following numerical values:—

$$(1,438 - 0.7 T_1) \left(\frac{T_1 - T_0}{T_1} \right) = 898 \times \frac{200}{771} = 233 \text{ units.}$$

$$T_1 - T_0 = 771 - 571 = 200$$

$$T_0 \log_e \frac{T_1}{T_0} = 571 \times 0.3 = 171 \quad 29 \quad ,,$$

$$\text{Net Total} \quad 262 \quad ,,$$

This would be seen to agree with the value of the ordinate of the curve in *Fig. 2* for steam at 310° or 78 lbs. total pressure. To apply these numerical results to the somewhat abstruse $\theta \phi$ diagram, *Fig. 3*, let the latter be set out to convenient scales on sectional paper with the horizontal lines at heights above the zero baseline representing the respective temperatures of 571° and 771° . The vertical strip K + M contained an area equal to 200 units; being all the heat required to raise the water from the lower to the higher temperature. Let the rectangle L + N (*Fig. 3*) contain 898 units, representing all the latent heat without deduction. Next, taking into account the intersecting horizontal line at 571° temperature, the following values would be obtained for K + L respectively, viz.:—

$$K = 200 - 171 \quad . \quad . \quad . \quad . \quad = 29 \text{ units}$$

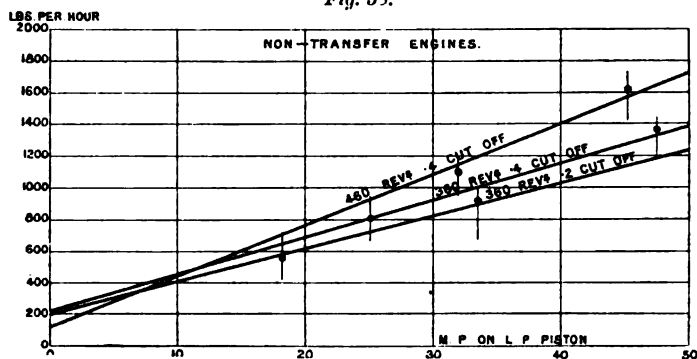
$$L = 898 \times \frac{200}{771} \quad . \quad . \quad . \quad . \quad = 233 \quad ,,$$

$$\text{Therefore the work in heat-units due} = K + L = 262 \text{ units, as before.}$$

He ventured to think that this illustration, by means of definite numerical values, would assist in showing the practical bearing of Mr. Macfarlane Gray's diagram.

Captain H. R. SANKEY, R.E. (retired), said he rose with some dif- Capt. Sankey. fidence to reply, but his task had been made comparatively easy by the kind manner in which the Paper had been received and discussed. The key-note of the discussion had been praise of the Author and his Paper, and he was certain this would be a source of

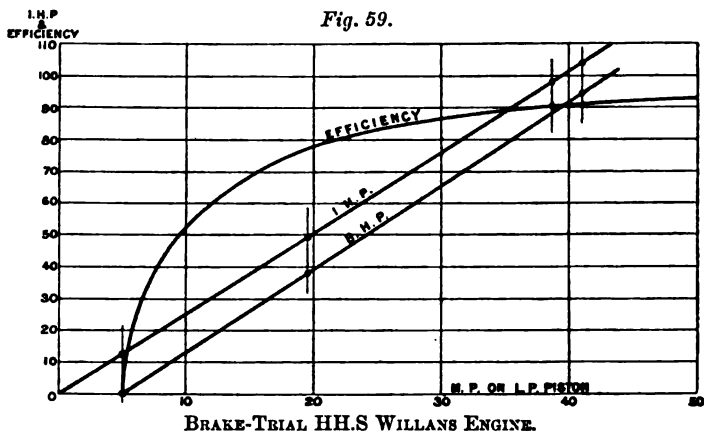
Capt. Sankey, gratification to the family of the Author, as it had been to himself and to his colleagues. One of the most gratifying features of the discussion had been the complete confidence which had been accorded to the results of these experiments, and he knew that the Author, had he been with them, would have felt more pleased with this than with anything else that had been said. It might, however, be interesting to have a verification of the accuracy of the testing-apparatus at Thames-Ditton, by a comparison with the tests made by Messrs. Sulzer Brothers, of Winterthur, with an ordinary "G G" Willans engine (80 I.H.P.), purchased by them last year. The results were shown in *Fig. 58*. The straight lines showed the average of many trials at Thames-Ditton, made with engines of the ordinary non-condensing type when working condensing, so that the absolute results were not so good as those given in the

Fig. 58.

Paper, which were obtained with an engine of the condensing type, as explained at page 2. The dots represented the tests made by Messrs. Sulzer, and it would be observed that they were very close to the corresponding Thames-Ditton results. The trials were made with all the care and precautions that might be expected from a firm of Messrs. Sulzer's reputation, and the water used was determined by weighing the condensed steam. Several questions had been asked referring to the effective power developed by the engine: Mr. Cowper wanted to know what quantity of water had to be evaporated for an effective horse-power free from all frictional and other losses; Mr. Davey asked whether any note had been taken of the effective power developed; and Mr. Beaumont wished to know the power required to drive the air-pump. The answer to all such questions was, that these trials had reference only to the behaviour of the steam under various conditions, and that it was

therefore quite immaterial whether the load on the engine was Capt. Sankey. internal or external, and for this reason no note was taken of the effective power developed. To ensure due accuracy in the trials it was essential that the load should be steady; hence the air-pump, involving, as was well known, an unsteady load, was not driven by the engine itself, but by another engine. But as the question of effective HP. had been raised, he would say that they had ample evidence from tests made with "steam-dynamos" that the efficiency of the Willans compound-engine was about 90 per cent. With some few unimportant exceptions, however, these results had been obtained from friction-cards, and by deduction from the combined efficiency of a number of steam-dynamos. A combined efficiency of 84 per cent. was frequently obtained, and taking the dynamo-efficiency at 93 per cent., this left a little over 90 per cent. for the engine. He had, however, been so pressed by Mr. Cowper after the reading of the Paper to make a brake-trial, that he had determined to do so, and he now had pleasure in bringing the results of this trial before the Institution. The trial had been made with an H.H.S engine, capable of developing 150 I.H.P., which was now on its way to drive one of the shafts at the Chicago Exhibition. A similar trial had been attempted with an engine of the I.I.S size, indicating 350 HP., also going to drive another line of shafting at the Chicago Exhibition, but unfortunately the brake-wheel was broken. The result of the trials with the H.H.S engine was shown graphically in *Fig. 59*. The I.H.P. obtained by measuring the diagrams was plotted on a mean-pressure base, and of necessity gave a straight line. The corresponding brake HP. points lay, it would be seen, sensibly in a straight line very nearly parallel to the former. The efficiency curve was given by these two straight lines, and the efficiency at four-fifths of full load (40 lbs. mean pressure) was shown to be 90.1 per cent. That afternoon another brake-power trial had been made with a smaller engine, a simple transfer engine, and he had just been handed the result. The results were again similar to those shown in *Fig. 59*, and the efficiency came out at very nearly 90 per cent. at full load. The brake used was of the ordinary rope type; the lower half only of the circumference was in contact with the ropes. One end of the strap was attached to a spring balance, and the other to a Denison weigher. It was unnecessary to enter into the precautions taken to ensure accuracy. When, however, the question at issue was only the commercial economy of a steam-dynamo, the simplest and best criterion was the water

Capt. Sankey. required per electrical HP. delivered by the dynamo. To ascertain this only three things had to be measured, namely, the total water-consumption per hour, the amperes, and the volts, and it was quite easy, with ordinary precautions, to make each of these measurements with errors not exceeding 1 per cent., so that the error of the combined measurements would be under 2 per cent. With the apparatus available at Thames-Ditton, the errors of such combined measurements were certainly within $\frac{1}{2}$ per cent. The remarks of Mr. Davey and of Mr. Crompton as to the effect of leaks, radiation, &c., on the economical results were of great importance; and, although from the point of view of the Paper not strictly an engine question, leaks and radiation were factors in determining the boiler-pressure at which it was economical to work. To illustrate this he

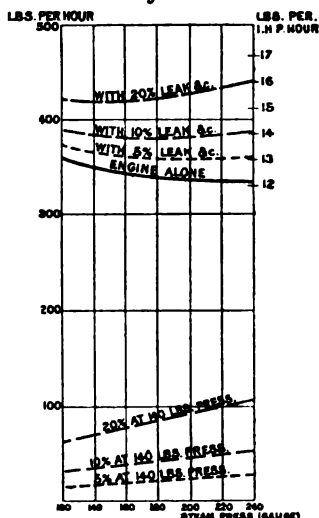


had prepared a diagram (*Fig. 60*); the curve "engine alone" showed the best results obtainable with the triple-engine when working with different boiler-pressures deduced from the trials under discussion. The I.H.P. for the engine was the same for all points of the curve, namely, 27.4. This curve might be conveniently called the best economy curve for the engine. As regards the losses in the boiler and steam-pipes due to radiation and leakage, he was not aware that any reliable data were available to determine the law connecting these losses with the steam-pressure for any given boiler or boilers, or system of steam-pipes; and he would therefore assume that those losses increased proportionally to the pressure, so that they would be represented by straight lines, as shown in *Fig. 60*, for the three cases taken for illustration, namely, a loss of 5 per cent., 10 per cent., and 20 per cent. at 140 lbs. gauge-pressure. By

adding the losses shown by these straight lines to the engine-curve, Capt. Sankey. the dotted curves, showing the actual consumption at various pressures, were obtained; and it would be noticed that for 5 per cent. loss (at 140 lbs. gauge-pressure) the total consumption was increased when working beyond about 190 lbs. gauge-pressure; for 10 per cent. loss beyond 160 lbs.; and for 20 per cent. beyond 145 lbs. A loss of 20 per cent. at 140 lbs. gauge-pressure was undoubtedly a very extreme case, but was nevertheless not impossible, judging from the remarks of Mr. Crompton, who said that in one case he had found these losses (combined, however, with the steam required for the feed-pumps and a mechanical-stoker) to be no less than 45 per cent. of the steam required by the engine. If reliable loss-curves for boilers and steam-pipes could be obtained, it would be possible, by combination with the engine-curve, to determine the most economical pressure to work at under any given set of conditions. It was, however, certain that for economy, a higher pressure could be used in the case of one engine with one short steam-pipe, than with a group of engines (at electric-lighting stations, for instance) connected to the boiler by long, many-jointed steam-pipes. This question

also required further study with regard to the increased cost of producing high-pressure steam, the possible reduction of boiler-efficiency at high pressures, and in particular the use of economisers. The question of jackets had been referred to by many speakers; on the whole, he thought it might fairly be said that a jacket was of great advantage to a low-speed engine, otherwise given to much initial condensation; but was of comparatively little use for a high-speed engine designed so that the temperatures were well divided and the cylinder-drainage good. A comparison of *Fig. 33* with *Fig. 34* threw some light on this point, for it seemed evident from the proportion of steam to water in the cylinders as shown by these figures that jackets would have improved the consumption of the engine when running at 100 revolutions (*Fig. 33*); but when the steam condensed in the jackets was taken into account, it did not seem that they could do much good when the engine was running at

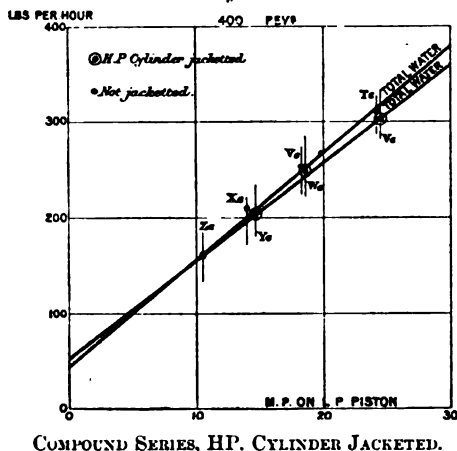
Fig. 60.



EFFECT OF LEAKS &C. ON CONSUMPTION.

Capt. Sankey. 380 revolutions (*Fig. 34*). Reference had been made by the Author (page 44) to some jacket-trials he had made: in one set the jacket was placed round the high-pressure (intermediate) cylinder (*Fig. 1*), and these trials had been plotted on *Fig. 61*, together with comparable non-jacketed trials.¹ It would be seen from this figure that with the addition of the steam condensed in the jacket reduced the advantage gained was inconsiderable. Some trials had also been made by the Author with what might be called a hood-jacket, as shown in dotted lines in *Fig. 1*. This jacket was not actually used with the present experimental engine; but with the engine with which the Author had made his non-condensing trials.² Those

Fig. 61.



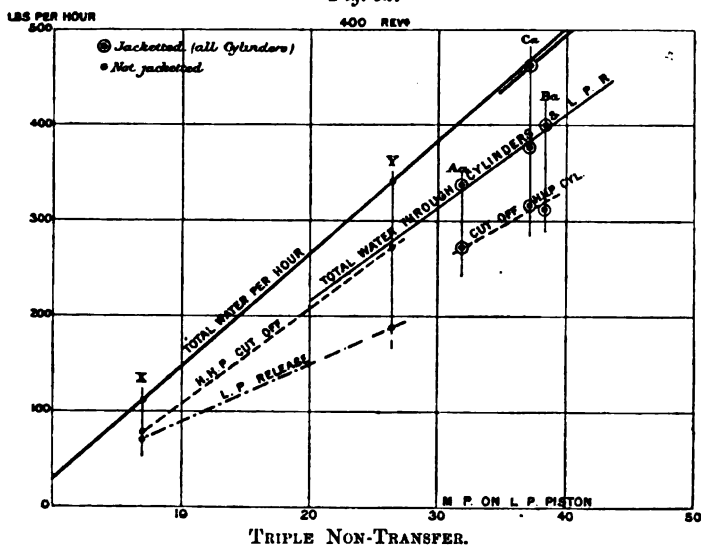
trials were shown in *Fig. 62*, together with two comparable non-jacketed trials, X and Y. It would be noticed that all the steam condensed at H.H.P. cut-off was re-evaporated at L.P. release. The steam condensed in this jacket was of course enormous (25 per cent. of steam going through the engine), so the only lesson to be learnt was as to the saving in the steam actually passing through the engine. The result of all these jacketed trials might be said, to be that with high-speed engines almost all the saving in the steam going through the engine was lost in the steam condensed in the jacket itself.

¹ None of these trials were given by the Author in Appendix III.

² This engine was exhibited at the President's reception on the 18th of April, having been cut in two to exhibit the motion and the steam-distribution.

He quite agreed with Mr. Davey that water would lie at the bottom of the receivers of the engine. As a matter of fact, in the new condensing-engines now being designed, arrangements had been made to prevent this. In this connection a copper coil would have the effect of more or less drying the steam, and to test this point he made four experiments last winter. The water per I.H.P. was slightly in favour of the jacket coil, namely, 15·89 lbs. per hour, as against 15·97 for the non-transfer engine and 14·93 against 15·02 for the transfer engine, and the drying effect of the coil was clearly shown by the steam present at cut-off in the low-pressure cylinder being increased about 8 per cent. Attention had

Fig. 62.



been drawn by Mr. Davey to trials C₄ and D₄ to show that only one-seventh of the feed-water was saved by increasing the pressure from 55 lbs. to 130 lbs. in the triple engine. It was to be observed that the water theoretically required per I.H.P. (line 34) is 9·5 lbs. and 8·22 lbs. in the two cases respectively, showing a theoretical gain of $\frac{1}{7}$ th, so that the actual engine followed the theoretical engine. It should be noticed also that in trial C₄ the corrected ratio of expansion was 14·10 (line 11), and that the total mean pressure referred to the low-pressure piston was only 10·84 lbs. per square inch, so that very little power was got out of the cylinders, and the consumption per brake HP. would be correspondingly

Capt. Sankey. increased. In other words, the expansions were carried too far in trial C_4 for practical purposes, and from this point of view trial D_4 , requiring 13.39 lbs. of feed per hour, ought to be compared with trial L_3 , requiring 18.25 lbs. per hour, or even with trial E_5 , requiring 24.03 lbs. per hour. This illustrated very forcibly how excellent results per indicated HP. could be obtained at the expense of increased consumption per brake HP. and increased initial cost of the engine; a point, it was believed, not infrequently lost sight of. This later argument also dealt with Mr. Davey's remark, that trials C_4 and D_4 showed that *Fig. 7* did not correctly show the limit of useful ratio of expansions. This figure had reference to the economical results per brake HP., inasmuch as T_2 (page 12) took into account the friction of the engine; but it appeared needless to say anything further on this point as Dr. Hopkinson had made the matter quite clear in his remarks. The remark of Mr. Davey that in all results there was shown to be a very large percentage of water, appeared to require some qualification, because a considerable portion of the condensation was due to work done. To illustrate this, two of the trials had been selected and compared with a perfect engine working between the same limits. The respective percentages of water present at various points in trial E_4 were as follows:—

—	H.H.P.		H.P.		L.P.	
	Cut-off.	Release.	Cut-off.	Release.	Cut-off.	Release.
Actual engine . .	12.92	10.93	17.06	14.35	34.86	26.46
Perfect engine . .	0	5.17	7.73	10.00	13.30	16.00

In trial N_3 , however, conditions were so arranged as to produce a great deal of initial condensation, and in this case there resulted—

—	H.P.		L.P.	
	Cut-off.	Release.	Cut-off.	Release.
Actual engine . .	30.83	14.07	36.20	25.32
Perfect engine . .	0	10.00	13.30	17.20

In this connection it might be interesting to point out that if the results given in lines 48 to 53 of the Tables were plotted, it would be

found that the condensation at the point of cut-off in each cylinder, Capt. Sankey. and the subsequent re-evaporation at the end of the stroke, not only depended on the range of temperature of the cylinder, but also on the actual temperature of the steam, and was greater the higher the temperature, and to a very marked extent. The remarks that had been made on the Cornish cycle by Mr. Davey were extremely interesting, and it was gratifying to the makers of the Willans engine, to hear that Mr. Davey had practically found this cycle to be the best; he thought much credit was due to him as being the moderniser of the Cornish cycle. This cycle had been from the very first employed by the Author in his central-valve engine in connection with the H.H.P. and H.P. cylinders; but he used it for the first time in the low-pressure cylinder in the engine with which these trials were made, and when thus applied it was called the transfer arrangement. In this connection it might be interesting to mention that a short time ago, when designing the new line of condensing-engines, he thought it was worth while to ascertain definitely the advantage of the transfer by making two trials with the experimental engine, one working with and another without the transfer arrangement. In order to make the comparison as definite as possible the transfer trial E_1 , was purposely arranged to compare with the Author's trial E_3 , and the result was a very close agreement even in some of the more delicate indicator diagram measurements. The non-transfer trial G_1 , was arranged to compare with E_1 , and showed a very distinct gain in favour of the transfer arrangement, namely, 15.97 as against 15.02 lbs. of water per I.H.P. per hour, and the same was true of two trials (F_1 , H_1) in which the coil in the receiver was used. Comparing the transfer trials with the non-transfer trials, the salient points of difference were these: the consumption was less, the thermal efficiency was greater, and the initial condensation was less. Trials had been made by the Author with the engine working as a simple transfer and as a simple non-transfer. These trials proved, as might be expected, that the transfer arrangement had more influence in a simple than in a compound engine. In one case, for instance, the water per I.H.P. was reduced by the transfer from 29.31 to 26.19 lbs. In the Paper and elsewhere, the Author had expressed the opinion that the drop of pressure at the toe of the diagram tended to dry the cylinder-walls, and to considerably reduce initial condensation. It seemed reasonable to suppose that the condition of the cylinder-walls would affect the behaviour of steam during compression, so that, if the cylinder-walls were dry, they would expect less condensation than if the cylinder-walls were

Capt. Sankey. wet. The above trials threw some light on that point. With the transfer arrangement there was generally little or no toe to the low-pressure diagram proper, and it was found that steam was condensed during compression in the transfer trials; whereas in the non-transfer trials, where there was a toe to the diagram, evaporation took place during compression. On referring to the Tables, Appendix III, and comparing lines 101 and 102 it would also be apparent that, with very few exceptions, steam was condensed during compression.

The masterly exposition of the Willans law by Professor Kennedy had materially added to the value of the discussion. He would like, however, to point out that line G had another meaning; it was the consumption line of an engine working in an atmosphere hotter than the working fluid—for instance, a carbonic-acid-gas engine. In such a case heat would be radiated into the engine, and not out of it. It might also be interesting to attach a meaning to a consumption line sloping in the opposite

Fig. 63.

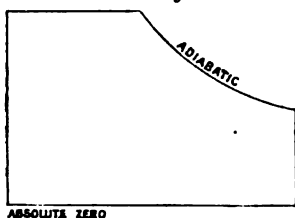
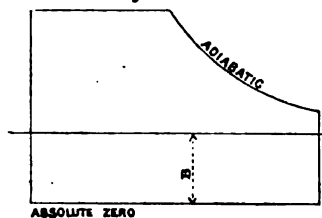


Fig. 65.

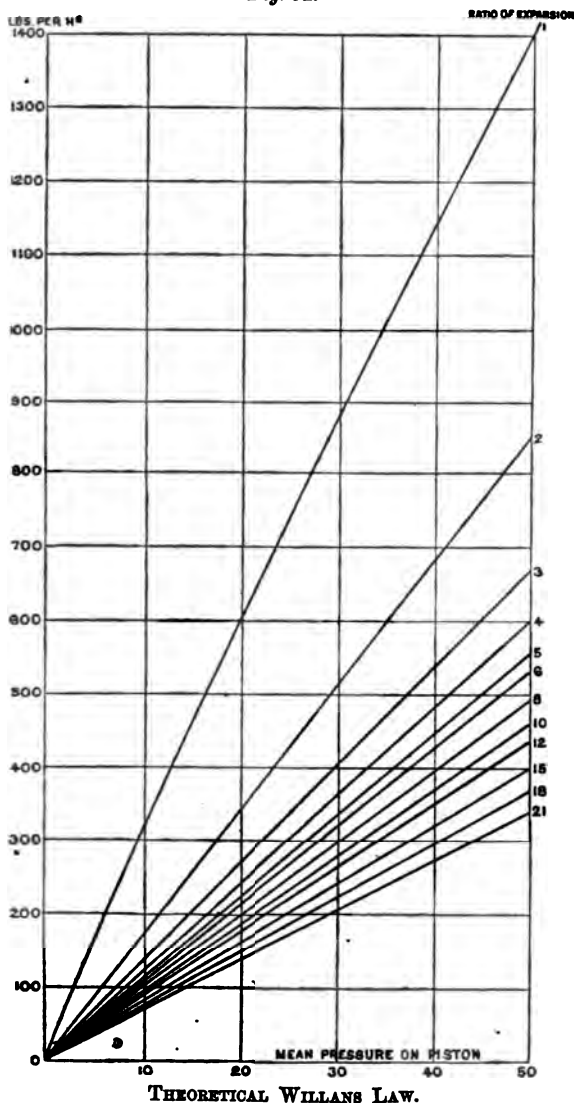


direction, in which case, the greater the mean pressure the greater the quantity of negative working fluid; this was evidently the case of a pump or of a compressor. The Willans law for oil-engines had not been shown by Prof. Kennedy. It appeared to be somewhat different from that for gas-engines, that was, there was a greater initial loss, possibly owing to the imperfect combustion of the oil when the engine was working at light loads. This had been remarked by the Author in the discussion on Prof. Unwin's Paper on "Petroleum Engines."¹ The Willans straight-line law was also found to hold for the original Willans three-cylinder engine, the steam-distribution in which was totally different to that in the central valve-engine, and was also true for the "Willans-Robinson-Scott" engine, another type of single-acting engine with an entirely different steam-distribution. In point of fact, the law held for a theoretical engine working at various loads

¹ Minutes of Proceedings Inst. C.E., vol. cix. p. 1.

with constant ratio of expansion. The diagram of such a theoretical engine could be supposed to be as shown in *Fig. 63*; the admission

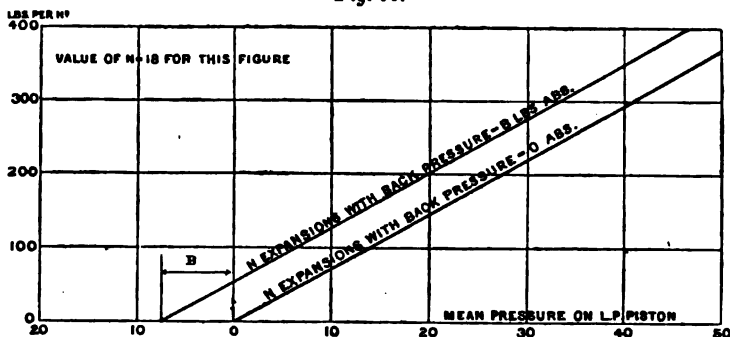
Fig. 64.



line was at constant pressure, the expansion adiabatic, the release instantaneous, the back-pressure absolute zero; there was no
[THE INST. C.E. VOL. CXIV.]

H

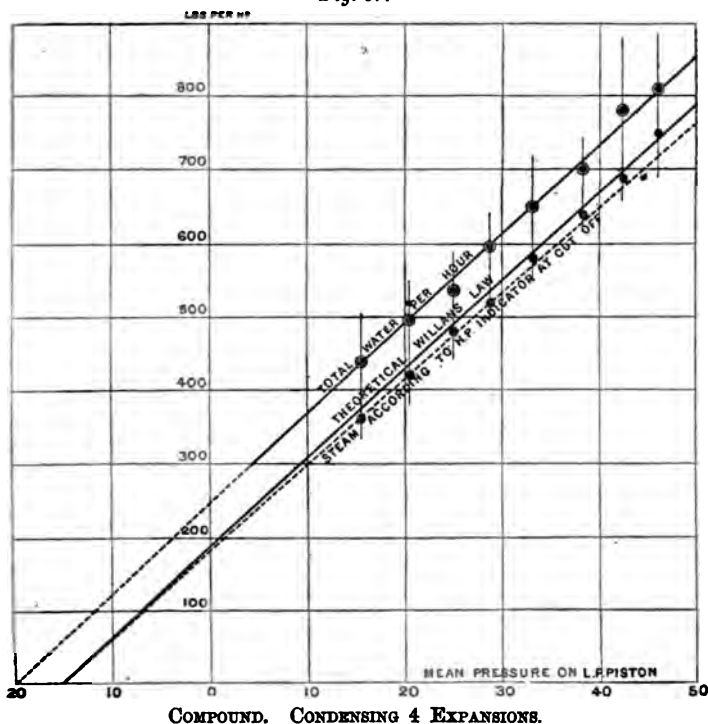
Capt. Sankey. compression and no clearance, and initial condensation, radiation, and all other losses were supposed to be nil. The steam shown by the indicator at cut-off, which would also be the feed, and the mean pressure of such a diagram, could be obtained in the usual way, and if this was done for a series of such diagrams, differing only as regards steam-pressure, that was, with constant ratio of expansion, it was found that if the total steam per hour shown by the indicator at cut-off were plotted on a mean-pressure base, the result was a straight line, or, more strictly speaking, a curve so flat that it was indistinguishable from a straight line. A series of such lines for different ratios of expansion could be drawn, as was shown in *Fig. 64*. It would be noticed that for a ratio of expansion of one (that was, with no expansion) the curvature of the line was somewhat marked. If instead of zero the back-pressure was B lbs. per square inch, as

Fig. 66.

shown in *Fig. 65*, it was evident that the steam shown by the indicator remained the same as before, but that the mean pressure was reduced to the extent of B lbs. per square inch. The consumption line for x expansions in this case would therefore be parallel to the corresponding consumption line for zero back-pressure, at a horizontal distance B lbs. per square inch from it, as given in *Fig. 66*. This proved that the distance between the zero of mean pressure and the intersection of any consumption line with the mean pressure base, was equal to the back-pressure. It had been thought originally by the Author that the total feed-line intersected the base line at a distance equal to the back-pressure from the origin, but he soon gave this idea up. Mr. Wingfield, referring to Figs. 27 to 30, suggested that this might be true of the steam shown by the indicator at cut-off. It appeared from the above, however, that this was true of neither the one nor the other, but

that it was true for the steam shown by the indicator of a theoretical **Capt. Sankey.** engine. Captain Sankey thought that possibly valuable information might be obtained by comparing the actual lines shown in Figs. 11 to 24 with the corresponding theoretical lines, and for this purpose he was having them plotted on the large scale drawings which the Author had originally prepared when writing this Paper. It was, however, *à priori*, evident that the actual feed-line must in all cases lie above the corresponding theoretical consumption line.

Fig. 67.

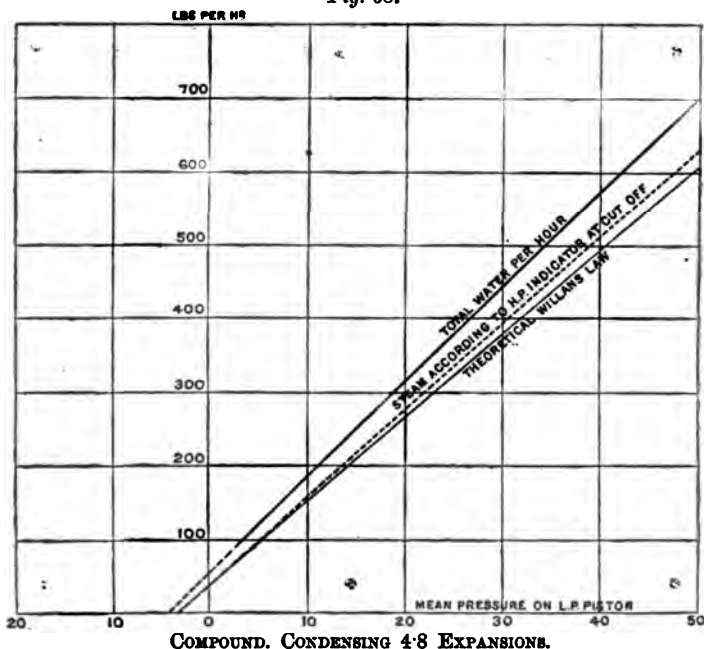


As regards the line for the steam shown by the indicator at cut-off in the first cylinder (H.H.P., H.P. or L.P., as the case might be) initial condensation tended to place it below the theoretical line; inasmuch as the steam initially condensed was, at any rate, partially re-evaporated later on in the expansion, and fattened the toe of the diagram, thus increasing the mean pressure. Radiation, conduction and leakage, on the contrary, tended to place the line above the theoretical line. Conditions might, therefore,

Capt. Sankey. evidently be such that the two lines coincided, or, again, that, although not coinciding, they might intersect the base at the same point.

Figs. 67 and 68 gave two examples, comparing the theoretical Willans law with corresponding feed-lines and also with the steam-lines at H.P. cut-off; in either case the engine was working compound, but in one case as a non-condensing engine, and in the second as a condensing engine. *Fig. 67* had been obtained by plotting the results given in Table VII of the Author's trials on

Fig. 68.



non-condensing engines,¹ and it was interesting to note that, as might be expected, observation-points for steam at H.P. cut-off lay as near the straight line in that case as they did in the various cases given in the present Paper, *Figs. 11 to 24, Plate 1*; but the observation-points for the feed did not agree nearly so well with the fair line as in the present condensing trials; that could only be attributed to the different and inferior method employed for measuring the consumption, viz., by weighing the feed-water

¹ Minutes of Proceedings Inst. C.E., vol. xciii. p. 54.

into the boiler, even though all possible precautions were taken to Capt. Sankey. ensure accuracy. This must be looked upon, therefore, as another proof to be added to the many already adduced that the method of weighing the condensed exhaust is more accurate than weighing the feed into the boiler, at any rate for an engine where glands are as tight as those of the Willans engine. It had been also suggested by Mr. Wingfield, that the point where the various lines, showing steam according to the indicator in Fig. 27, Plate 2, cut the base line "would prove to be at a distance equal to the mean back-pressure from the origin." It followed from the above that it might be so under certain circumstances; as a matter of fact it was not so in the case referred to—the point lay about $\frac{1}{4}$ lb. per square inch further from the origin than the mean back-pressure. The various lines were, however, correctly drawn through a point, because the element of change in these lines was the number of revolutions per minute, which would clearly have but an inappreciable effect on the position of their intersection with the base line. These latter remarks applied also to the point where the total-consumption lines intersected. On further considering this matter, he had come to the conclusion that the feed-line and the HP. cut-off line curved downwards at very low and negative mean pressures, and would intersect the base at a point nearer the zero of mean pressure than the intersection of the theoretical Willans law, but for want of space was unable to give his reasons. In reply to Mr. Wingfield the method employed for measuring the diagrams was to use a drawing-board, to which a small piece of paper had been pinned, and the tracing-point of the planimeter was placed on this paper at a point marked close to the edge; the first card was then slipped under the paper until some convenient point on the diagram was close to the tracing point. The area of the diagram was then planimeted, taking care to finish off with the tracing point in the same position on the piece of paper. The second card was then substituted, and so on. In this manner the planimeter was never lifted, and the combined area of all the cards was taken at one reading. The theoretical mean pressures (reckoned for adiabatic expansion and given in line 27 of Tables I to IV) against the actual mean pressure (given in line 25), it was found that the points also lay in straight lines, the position of each straight line depending on the number of expansions and upon whether the engine was simple, compound or triple; but all passed through the origin, so there was no virtual back pressure to estimate. The tangent of the angle included between these straight lines and the axis of abscissæ was a true diagram-factor in the sense that it was

Capt. Sankey. also an efficiency. The theoretical mean pressure, reckoned on adiabatic expansion, could be more easily obtained for any given conditions of working of the engine from the $\theta \phi$ diagram by the help of the planimeter than by calculation from the formula given by Mr. Wingfield. He had been much interested in Mr. Wingfield's method of predicting the mean pressure of an engine, but he had found on plotting and by applying the corresponding diagram-factor the actual mean pressure could be predicted; space did not, however, permit going into the details of the process.

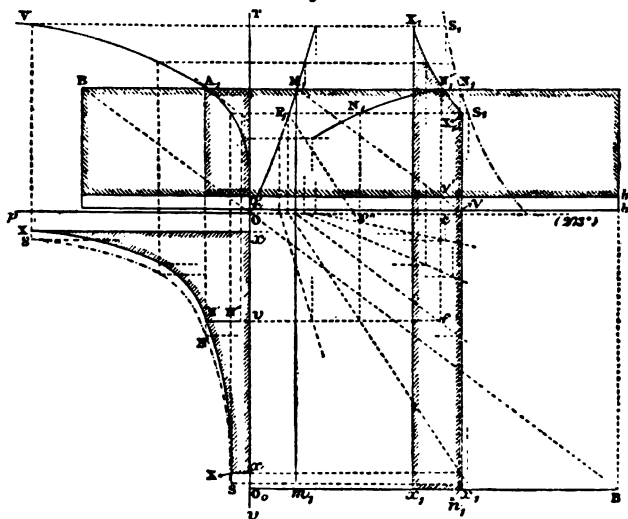
It had been suggested by Mr. Beaumont that a term was required for expressing the commercial efficiency of an engine in contradistinction to its thermal efficiency; but surely the water per indicated HP., or more strictly, per brake HP., gave the information needed on this point. Conceivably, however, an expression for the commercial value of an engine might be obtained on some such considerations as the following:—The horse-power developed would be in the numerator, and the denominator would comprise the cost of evaporating the feed, the cost of lubrication, the cost of maintenance and repairs, the cost of attendance, depreciation and interest on first cost, &c. Brake-trials to ascertain "at what point the triple-expansion advantages were lost in the disadvantages connected with that form" in the Willans engine would be made; but it was to be observed that such experiments would not throw much light on the general question, because the Willans engine could be changed from compound to triple expansion by the simple addition to each line of parts of one small cylinder and its valve, and the additional friction was therefore small. The term "plant efficiency" had been questioned by Mr. Davey, but Mr. Macfarlane Gray had explained the meaning of the term, so that it did not appear necessary to say anything further. The latter speaker had also introduced a new term which he called "engine efficiency," and it might at first sight appear that this efficiency was the same as that used by Prof. Osborne Reynolds, and to which the Author objected strongly (Appendix V); but there was a distinct and important difference, for Prof. Reynolds took the pressure at release at the same point as in the engine under review; and, as pointed out by the Author, this involved getting the best efficiency from a square diagram without expansion. The terminal pressure would, however, be fixed by Mr. Macfarlane Gray at some value obtainable under the best conditions in practice, and then exclude the resulting toe. In this manner any trial was compared with the theoretical result obtainable with a theoretical, but nevertheless possible, engine. The standard of efficiency pro-

posed by Mr. Macfarlane Gray had thus the advantage of being Capt. Sankey's a possible standard; and in this respect was not open to the objection the Author so strongly raised in his former Paper against taking the Carnot-cycle as the standard of efficiency. The difficulty, however, was in fixing the terminal pressure. For the purposes of the Paper the Author had fixed a pressure corresponding to 170° Fahrenheit, although he did not use this figure in calculating thermal efficiencies (p. 9), but others might disagree with this figure. If Mr. Macfarlane Gray's proposition were agreed to—and it seemed desirable that it should—some authoritative statement would be necessary on the point. In conclusion, he would like to remark that one of the most noticeable features in the whole Paper was the extreme modesty with which the Author had brought forward his results, and the entire absence of any claim to credit on behalf of the admirable engine he had designed, but which he described merely as a piece of apparatus employed in making experiments of purely thermodynamic interest. He believed that his name would remain with them not principally as the designer of the Willans engine, but as the Author of this and other Papers of deep scientific interest, and he would venture to add, as the discoverer of what he felt would henceforth be known as the "Willans Law."

Correspondence.

Prof. J. BOULVIN observed that the experimental results arrived at by the Author disagreed in no respect from the conditions established by the science of thermodynamics, if not quantitatively, at least qualitatively. The facts presented did not admit of discussion; and it was only by subsequent practice that the value of the data contained in the Tables appended to the Paper could be fully appreciated. The Author had been well advised in stating the results by the medium of the $\theta \phi$ diagram. In section E, it would have been useful to develop somewhat the method employed to find the losses due to wire-drawing (see, for instance, the hatched surfaces between the temperatures T_1 and T_2 , T_3 and T_4 (*Fig. 32*)). Similarly, the energy given as lost below temperature T_5 (*Fig. 34*), was possibly shown correctly by the shaded portions of the figure, but the Author's explanations were too far summarised to allow of verification. It might be interesting to show here how the lines of transformation of the

Fig. 69.



employing Clapeyron's equation—

$$r = \frac{1}{E} T \frac{dp}{dT} (u' - u),$$

r being the heat of vaporization, and E Joule's equivalent, it was

¹ *Vide Annales de l'Association des Ingénieurs de Gand, tome xvi.*

evident that the length $M_1 N_1$, which was equal to $\frac{r}{T}$, was also equal to—

$$\frac{1}{E} \frac{dp}{dT} (u' - u).$$

Suppose that, measuring temperatures along the axis OT and pressures along the axis Op , the curve OV were traced giving the pressure as a function of the temperature. The point of the curve of pressure being at A , let the tangent at that point be drawn, making use of the values of $\frac{dp}{dT}$ calculated by Zeuner; also, through the point M_1 let $M_1 \nu$ be drawn parallel to that tangent, intersecting the side $N_1 \nu$ of the right-angled triangle.

Then
$$N_1 \nu = M_1 N_1 \frac{1}{\tan M_1 \nu N_1},$$

or
$$N_1 \nu = \frac{r}{T} \cdot \frac{1}{\frac{dp}{dT}},$$

whence
$$N_1 \nu = \frac{1}{E} (u' - u).$$

Draw through O the line BB parallel to the tangent at A , and construct the rectangle Bb having as height $N_1 \nu$ and as base $T \frac{dp}{dT}$; this would represent the heat of vaporization r . The heat equivalent to the external work, or $\frac{1}{E} p [u' - u]$, would be represented by the rectangle AC . The internal heat, or $r - \frac{1}{E} p (u' - u)$ would be expressed by the difference of the rectangles Bb , Ac . If the conversion of liquid into vapour was incomplete, the entropy of the mixture would be represented by the abscissa at the point N_1' . The reasoning would be the same as that above; but denoting the mixture by x , $N_1' \nu'$ would represent the products $\frac{1}{E} (u' - u) x$, &c. The latent heat would be indicated by the rectangles with hatched edges. Supposing that the line of entropic transformation of a mixture were sought at constant volume, N_1' being a point in this line: as every other point must give the same volume, it was only necessary to construct the triangle $P_1 \nu'' N_1'$, taking $N_1' \nu'' = N_1' \nu'$; N_1'' would be the point sought. In practice, the preceding constructions might be shortened; for example, by referring all points such as M_1 to the same base as

Prof. Boulvin. indicated in the lower part of the *Fig.*, whence, by cutting with a horizontal line the group of $\frac{dp}{dT}$, and projecting vertically the intersections upon the corresponding temperatures, it was easy to trace the curve of equal volume $N_1' N_1''$.

To find the curve of expansion for any given conversion, choosing a convenient scale, the quantity $\frac{1}{E} (u' - u) x$, denoted by lengths such as $N_1' v'$, represented the excess of the steam over the volume u of the liquid. Hence, to obtain the pressure and volume of the steam with reference to the axes Op , Ov (near the bottom of the *Fig.* 69), it was only requisite to take $Ov' = N_1' v'$: the point N' was thus found. As the quantities such as $N_1' v'$ were equivalent to lengths such as ef , it was apparent that the point N' was readily obtained by drawing a horizontal line through f and a vertical through A . The volume of 1 kilogram of the mixture being—

$$u + (u' - u) x,$$

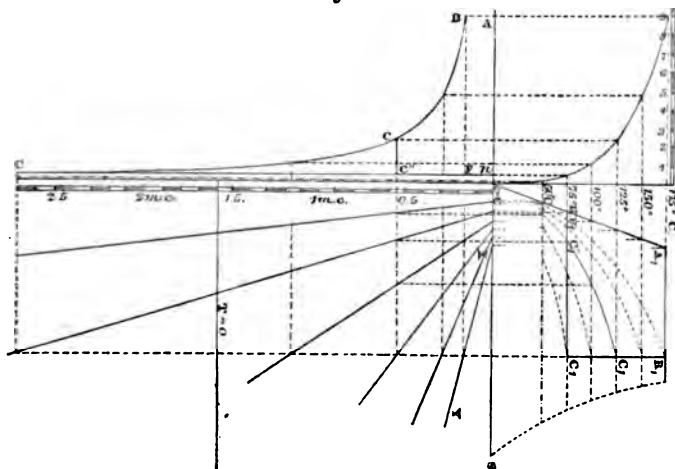
or

$$E \left(\frac{u}{E} + \frac{1}{E} (u' - u) u \right),$$

it was necessary, owing to the scale of the diagram, to raise the axis Op by the amount $\frac{u}{E}$; this second axis was not shown because it came too close to Op . In applying this construction for some points, it appeared that the curve of expansion XX corresponded with the transformation $X_1 X_1$; the shaded portion represented the heat converted into work during the transformation $XX n n$, and the heat furnished $X_1 X_1 x_1 x_1$, which was positive in the case considered. The curve SS was the line of expansion corresponding with the condition of saturation $S_1 S_1$ of the diagram of entropy, the point N corresponding with the condition N_1 . The foregoing construction was equally applicable to a line of compression and to one of expansion; it was also readily applicable to any weight of the mixture, since without altering the diagram, it sufficed to measure the entropy and the volume by means of a different scale which only depended on the weight of the mixture. To re-state more clearly certain of the relations just established, the diagram $ABC n$ (*Fig.* 70) corresponding with the diagram of entropy $KA_1 B_1 C_1$ was drawn for adiabatic expansion from the condition B_1 . By means of the group of straight lines XY selected from the values of $\frac{dp}{dT}$, lines of equal volume, such as $C_1' C_1''$, were rapidly

obtained. When there was no expansion, the diagram of work Prof. Boulvin. became reduced to the rectangle ABF , &c., regarding BF as a line of transformation at constant volume applying to a kilogram of the mixture; B_1F_1 was the corresponding transformation in the $\theta\phi$ system, and the heat rejected in the condenser was increased in the complete engine by the quantity $B_1C_1F_1$, &c. Indeed BF was not a transformation at constant volume; it was the line traced by the pencil of the indicator when the exhaust opened suddenly and the passages were very wide; but it could be shown that the energy lost at exhaust in actual work was the same as if all the vapour remained in the cylinder, to be there cooled at constant volume. Thus, the $\theta\phi$ diagram was conveniently drawn by this construction from the indicator-diagram; at least for the

Fig. 70.



periods of compression of expansion and of exhaust, provided that the weight of the working-fluid were known—a matter that presented no difficulty when a hypothesis was formed as to the nature of the fluid contained in the cylinder at the commencement of the compression. The only period with regard to which the $\theta\phi$ diagram could give rise to doubt, was that of admission when there was wire-drawing at the ports. For that period, which was not reversible, the progress of the condition of the fluid could not be followed on the $\theta\phi$ diagram; but the principle of equivalence allowed the internal heat to be found at the moment expansion began.

Mr. B. DONKIN, jun., thought the two sets of tests, non-Mr. Donkin.

Mr. Donkin. condensing and condensing, formed probably the most complete experimental series of the kind yet published on any type of engine, and formed a lasting monument to the memory of the Author. There was no similar set of steam-trials upon a much larger and more important class of high-speed engine, viz., the locomotive, notwithstanding that tens of thousands were in use in many countries. This was a remarkable omission in the case of a motor so extensively employed for "the use and convenience of man." Here was a great field of investigation for some Institution or Society, likely to lead to important practical results. These cylinders were not steam-jacketed, were much exposed to the weather, and the engines were constantly being stopped and started. For the modern scientific engineer, the weight of the coal used per mile was insufficient. Next, there was the extensive branch of slower-running marine engines. Here also, as regarded experimental facts, there was, until quite lately, a complete blank in most countries. During the last few years, Professor Kennedy had shown shipowners that accurate steam- and coal-tests could be readily made at sea. Fixed engines had been experimented on for the most part during the last few years in England, America, and on the Continent, and year by year the observations were becoming more accurate and reliable. For testing condensing or non-condensing engines, he agreed with the Author, that a surface-condenser afforded the best and most accurate way of obtaining the weight of the feed-water, allowing short and exact trials to be made. He hoped the indicator diagrams nearest to the mean would be added for each experiment, as in the Author's former Paper; and that all the results would be given graphically, particularly the percentage of water present at release. It was unfortunate that no observations were taken as to the temperature of the cylinder-walls. Many steam-temperatures were given, but not that of the metal near the steam, which was highly important. No experimental results were added relative to the indicated HP. required to drive the engine alone at the different speeds, say between 100 revolutions and 400 revolutions per minute. If this could be supplied, it would form an interesting addition. The indicated HP. seemed to be given, not at the actual speed of each experiment, but at the proposed speed. Mr. Donkin did not understand the reason of this; nor could he find in the Paper any experiments on the consumption of steam per indicated HP. per hour for the single, compound, and triple engine, made with the same steam-pressure, speed, and number of expansions. The nearest trials he had been able to find in the Author's series to

compare the compound with the single cylinder, both condensing, Mr. Donkin. were as follows; the speeds, steam-pressure, and expansion were, however, not quite the same:—

SINGLE CYLINDER.— H_5 ; 4 expansions; 29 I.H.P.; 382 revolutions per minute; $23\frac{1}{2}$ lbs. of steam per I.H.P. per hour; steam-pressure, 75 lbs. absolute; water present at release, $22\frac{1}{2}$ per cent.

COMPOUND.— L_2 ; 5·7 expansions; 404 revolutions; 18·7 I.H.P.; 18 lbs. of steam per I.H.P. per hour; steam-pressure, 64 lbs. absolute; water present at release, 16 per cent.

In comparing these experiments, the number of expansions and speed were in favour of the compound engine, but the steam-pressure was against it. In steam-consumption per I.H.P. per hour the result was 23 per cent. in favour of working compound, and the steam was considerably dryer at the exhaust, some $6\frac{1}{2}$ per cent. In all the experiments there was a good deal of water present at release, 20 to 25 per cent. in the best. The maximum economy had not therefore been reached, as the mixture should be exhausted practically dry to the condenser. This pointed to steam-jacketing, or the use of superheated steam in the future. Taking the best experiments in each series of the three types of engine-tests, condensing, the following were the broad results:—

SINGLE CYLINDER.— I_5 ; 85 lbs. steam pressure absolute; 4 expansions; 383 revolutions per minute; steam per I.H.P. per hour, 22·16 lbs.; $33\frac{1}{2}$ I.H.P.; steam missing, or water present at release, 19 per cent.

COMPOUND ENGINE.— N_3 ; 175 lbs. steam pressure absolute; nearly 16 expansions; 402 revolutions per minute; steam, per I.H.P. per hour, $14\frac{1}{2}$ lbs.; $27\frac{1}{2}$ I.H.P.; water present in low-pressure cylinder at release, $25\frac{1}{2}$ per cent.

TRIPLE.— G_4 ; 184 lbs. pressure absolute; 14 expansions; 384 revolutions per minute; steam per I.H.P. per hour, nearly $12\frac{1}{2}$ lbs.; 30 I.H.P.; water in low-pressure cylinder at release, $22\frac{1}{2}$ per cent.

He knew of many excellent tests of single-cylinder condensing steam-jacketed engines, indicating 70 to 100 horse-power, double-acting, which, according to repeated trials by independent experts, consumed only $15\frac{1}{2}$ to $16\frac{1}{2}$ lbs. of steam per I.H.P. per hour, with saturated steam of about 100 lbs. per square inch boiler-pressure. The water present at release was only 10 per cent., the mechanical efficiency being 90 to 92 per cent. With the Sulzer type of engine, condensing, the following were some of the best published actual tests by independent observers, with saturated steam: Single-cylinder, steam-jacketed, 18 to 19 lbs. of steam per I.H.P. per hour; pressure of steam, 70 to 80 lbs. per square

Mr. Donkin. inch. Compound engine, steam-jacketed, $13\frac{1}{2}$ to 14 lbs. of steam per I.H.P. per hour; pressure, 80 to 100 lbs. per square inch. Triple engine, steam-jacketed, $11\frac{3}{4}$ to 12 lbs. of steam per I.H.P. per hour; pressure of steam, 100 to 150 lbs. per square inch. These were, with engines indicating 200 to 600 horse-power, at ordinary mill-engine speeds, the piston-speeds being 400 to 600 feet per minute.

Mr. Schönheyder.

Mr. W. SCHÖNHEYDER mentioned, in regard to the important point of jacketing, that he had on several occasions, in the Institution and elsewhere, pointed out the small benefits which might generally be expected to result from the application of steam jackets to high-speed engines, and also the reasons for this. From the statement on page 44 of the Paper, the Author evidently did not expect great advantages in this direction. But the disability under which a high-speed engine suffered, in that it possessed too small a surface for transmitting with sufficient rapidity the required amount of heat from the jackets to the working steam, might be reduced in several ways. Thus, the outside of the cylinders, which would receive heat from the jacket-steam, might be furnished with heat-ribs, as first applied successfully by Mr. Druitt Halpin; and, in addition to these, the inside chambers (forming the receivers) might be similarly ribbed, to assist in giving up the heat received from the jackets through their ribs. By these means, the jackets could probably be made some three times as effective as was now possible without ribs. Further, hot flames instead of steam could be caused to surround the cylinders in the manner arranged experimentally by Mr. Bryan Donkin, jun.¹; or the jackets could be filled with mineral oil, circulated at temperatures of as much as 500° F., in addition to the use of the heat-ribs. In this manner heat could be obtained without inconvenient pressure, the higher temperature would, to some extent, compensate for smallness of surface, and even a moderate amount of superheating might be obtained.

Professor Schroeter.

Professor SCHROETER, of Munich, observed that the following historical remarks were not in the least intended to detract from the merits of the Author, or of any other English writer on the subject. He felt bound to claim some space in the Proceedings of the Institution to demonstrate that the graphical method introduced in England by Mr. Macfarlane Gray under the name of the " $\theta \phi$ diagram" was in reality of older date. It had been used for the first time in Germany by Mr. Linde, when professor of

¹ Minutes of Proceedings Inst. C.E., vol. xviii. p. 250.

applied mechanics at the Royal Polytechnikum at Munich, as far Professor back as 1874, and had been published by him in the "Verhandlungen des Vereins zur Beförderung des Gewerbflusses in Preussen" for 1875. In that

Paper, Professor Linde gave an application of the diagram to the theory of refrigerating machinery. Fig. 71 was reproduced from a photograph of a wall-map used by Professor Linde in his lectures on steam-engineing since 1874, and would give an idea of an early application of the diagram to the demonstration of the losses in the actual steam-engine process, as compared with Carnot's cycle. As Prof. Linde's successor since 1879, he never let a year pass without directing the attention of his students to this valuable aid in the study of thermodynamic machinery. Its usefulness could indeed not have been better proved than by the fact of its independent re-invention in England, and its adoption by Cotterill, Willans and others. He was very glad to see from a Paper by Mr. Richmond, in Vol. xiii. of the "Proceedings of the American Society of Mechanical Engineers," that the use of the method was spreading also in America.

Captain H. R. SANKEY, R.E. (retired), in reply to the cor- Capt. Sankey. respondence, said that his contribution to the discussion had been so lengthy, that he did not venture to do more than call attention briefly to two points that had been raised. The method proposed by Professor Boulvin, of drawing constant-volume lines on the $\theta \phi$ diagram was very elegant, but these lines could also be obtained by plotting the volumes of saturated steam on the saturation-line; and, with this as a basis, points on the constant-volume curves could easily be obtained. For over a year he had been using a $\theta \phi$ diagram

Figs. 71.

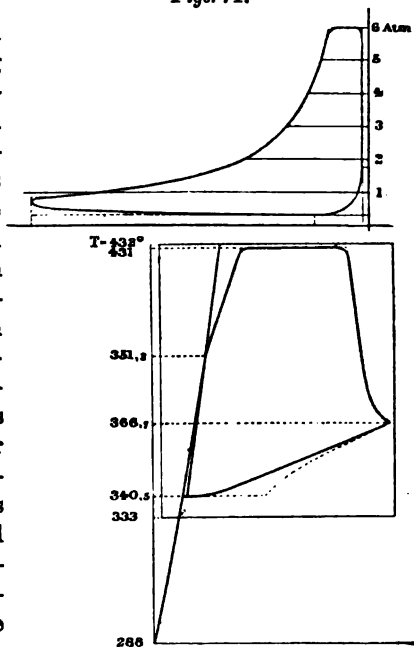


Diagram of "Heat-Weights."
SINGLE CONDENSING ENGINE WITH
SULZER GEAR.

Capt. Sankey. on which constant-volume curves had thus been plotted, together with constant-pressure lines, and had found it of the greatest use in solving thermo-dynamical problems of practical importance in the designing of engines. The graphic construction given by Professor Boulvin for finding the $p v$ diagram corresponding to a given transformation on the $\theta \phi$ diagram was interesting; but he would observe that it was not this, but the inverse problem, that presented itself for solution in practice. The $p v$ diagram was traced by the indicator, and to apply Professor Boulvin's method, would necessitate re-drawing this diagram to the scale required by the $\theta \phi$ diagram, in order to obtain the corresponding transformation. The problem had been solved by the Author, by calculating the steam shown to be present by the indicator diagram at a number of points in the expansion, but the calculations were lengthy, and Captain Sankey had been endeavouring for some time past to replace these calculations by a graphic method. The difficulty was how to deal with the receivers in compound and triple-expansion engines, and more especially with the "play-steam," to which Professor Boulvin did not refer, and which his method apparently did not deal with. The second point to which he wished to refer was Mr. Donkin's statement that "the maximum economy had not therefore been reached, as the mixture should be exhausted practically dry to the condenser." He was obliged to disagree with the latter part of this statement, and would even go so far as to say that in a high-speed engine a large "dryness fraction" at release was in many cases only an evidence of bad design of the engine—the result per I.H.P. might be good, but the result per B.H.P. would be bad. Space did not permit of his enlarging on this matter, and he would therefore content himself by referring to the Author's remarks at p. 238, Vol. xciii. of the Minutes of Proceedings.

18 and 25 April, 1893.

Mr. HARRISON HAYTER, President,
in the Chair.

The discussion on the Paper on "Steam-Engine Trials" occupied both evenings. On the 18th April the President and Council held the fourth Monthly Reception of the Session.

LIST OF MODELS AND APPARATUS

EXHIBITED AT THE MONTHLY RECEPTION, APRIL 18, 1893.

Exhibitor.	Objects.
W. ADAMS, M. Inst. C.E. . . .	"Boyer" Speed-indicator and Recorder. Model of "Adams" vortex blast-pipe for locomotive-engines. Model of metallic packing for piston-rods, as used on the London and South Western Railway.
BABCOCK & WILCOX	Model of boiler.
BEYER, PEACOCK & Co. . . .	Model of electric motor.
PETER BROTHERHOOD, M. Inst. C.E.	Latest pattern 3-cylinder engine.
CLAYTON & SHUTTLEWORTH . .	Set of "Tyrrell & Deeds" governors.
CROSBY STEAM-GAGE & VALVE COMPANY.	"Crosby" indicators (2).
H. M. DE-ATH	Model of "Robey" engine and vertical boiler combined.
DEWRANCE & Co.	Automatic water-gauge. "Bourdon" pressure-gauge.
EASTON & ANDERSON	Model and drawing of "Grafton" high-speed engine.
GRESHAM & CRAVEN	Model of combination-injector.
R. & W. HAWTHORN, LESLIE & Co.	Model of a tandem compound high-pressure engine.
EDWARD HAYES, M. Inst. C.E. .	Crosshead for compound surface-condensing engine. Marine-engine piston-rod, with crosshead and adjustable brass slides. Connecting-rod, with lubricator.
JEREMIAH HEAD, M. Inst. C.E.	Moving diagram of "Hackworth" valve-gear, adapted by Mr. Head and Messrs. Davy Brothers to reversing rolling-mill engines.
HEENAN & FROUDE	Spherical engine, with inside motion and two working models.
JAMES HOLDEN, M. Inst. C.E. .	Combined liquid-fuel injector and air ejector. Copper stays. Section of wheel-rim, tyre and retaining-ring. Standard piston and packing. Standard slide-bar and crossheads. Steel firebox. Variable blast-pipe. Drawings of locomotives and of various parts.
LEEDS FORGE COMPANY	"Fox's" corrugated furnaces. "Fox's" pressed-steel frame rolling-stock. "Morison" suspension furnaces.

Exhibitor.	Objects.
RICHARD FRÈRES	Self-recording and indicating pressure-gauge. Tachometer.
ARTHUR RIGG	Model of revolving-engine. Set of cylinders and valve-face.
ROBEY & Co.	Model of "Robey" engine and locomotive boiler combined.
ROYAL NAVAL COLLEGE, GREENWICH.	Model of annular-cylinder engine, patented by Joseph Maudslay in 1856. Model of direct-acting engine. Model of side-lever engine for paddle-steamer.
SCHÄFFER & BUDENBERG . .	Tachometers (2). "Thomson" indicators (2).
JAMES SIMPSON & Co. . . .	Working model of a beam pumping-engine erected at the West Middlesex Waterworks, Hammersmith.
SIMPSON, STRICKLAND & Co. .	Quadruple engine.
ARTHUR L. STRIDE, M. Inst. C.E.	Link motion of locomotive.
STEPHEN H. TERRY, Assoc. M. Inst. C.E.	Working model of "Aveling and Porter" 6 HP. road-locomotive.
Professor W. C. UNWIN, M. Inst. C.E.	Photographs (8) of the steam-engine with which G. A. Hirn made his researches at Colmar from 1854 to 1860. Portrait of Hirn.
WILLANS & ROBINSON, LTD. .	Working section of a "Willans" engine. (G-sized engine with which Mr. Willans made his non-condensing trials.) Hollow piston-rod of a 180-I.H.P. engine taken out after five years' work, on compounding the engine, showing no wear. Upper part and crank-shaft of a 60-I.H.P. (F.F.) engine, which had been driving Messrs. Willans and Robinson's works up to one o'clock on the day of exhibition.

2 May, 1893.

HARRISON HAYTER, President,
in the Chair.

It was announced that the several Associate Members here-
under mentioned had been transferred to the class of

Members.

FREDERICK JOHN DICK.	JAMES ROBERT ROBERTSON.
EDWARD DIMMACK MARTEN, M.A.	HENRY ALEXANDER GEORGE SHERLOCK.
THOMAS STEWART.	

And that the following Candidates had been admitted as

Students.

BENJAMIN BAGLEY COUSTON.	WILLIAM GORDON JONES.
WALTER JAMES HUTCHINSON.	HARRY MORRIS.
JOHN THOMAS SHIELD.	

The Candidates balloted for and duly elected were : as

Members.

JAMES FOSTER CROWELL, M.C.E.	HENRY LEA.
MARK HEATON ROBINSON.	

Associate Members.

FREDERICK WILLIAM ABBOT.	DUGALD McLELLAN.
JAMES PATTEN BARBER.	WILLIAM McNEILL, Wh.Sc., A.R.S.M.
NARCISO PUIG DE LA BELLACASA Y SANCHEZ.	VINCENZO MERCECA.
JOHN RICHARD BLACKER, Stud. Inst. C.E.	HARRY WILLIAM MILLER.
FREDERICO WILLIAM COX.	ARTHUR EDGAR NEWTON.
FREDERICK GEORGE DUNDAS DUENFORD.	HORMUSJI NOWROJI, B.C.E.
HENRY LAVINGTON FLETCHER, Stud. Inst. C.E.	GILBERT THOMAS INGLIS OLIVER.
FRANCIS BREAKEY FREEMAN.	WILLIAM ERNEST YOUNG PUTMAN, Stud. Inst. C.E.
RUPERT SKELTON HAWKINS.	WILLIAM HENRY REVILL.
CLAUDE WILLIAM HILL.	HENRY THORNTON RUTTER.
THOMAS HOLGATE.	PERCY STILL, Stud. Inst. C.E.
WILLIAM JOHN HOLLINGSWORTH.	LUCAS THOMASSON, Stud. Inst. C.E.
FRANCIS MADDISON LONG, Stud. Inst. C.E.	ARTHUR MAY TIPPETT.
	EDWARD HYDE ROBERT WYBRANTS WADE.
	BROOKE MIDDLEMORE WHITHARD.

(Paper No. 2609.)

"Mining and Ore-Treatment at Broken Hill, N.S.W."

By **MATHEW BUCHAN JAMIESON**, Assoc. M. Inst. C.E., and
JOHN HOWELL.

THIS Paper deals with the history and development of the Broken Hill Proprietary Company's Mine, the character and extent of the ore-bodies, and the methods adopted in mining and in the extraction of the metals. From this single mine, silver and lead to the value of over £8,700,000 sterling have been taken within about seven years; and it continues to yield about 220,000 ounces of silver, and between 600 and 800 tons of lead per week.

The first mention of the property in the records of the Mining Department of New South Wales is dated the 6th September, 1883, and is the application for a mineral lease by C. Rasp, D. James, and James Pool, for Block 12. Applications were lodged two days later for Blocks 11, 13, 14, and 15, and for Blocks 10 and 16, on the 21st September of the same year. Leases were granted by the Department of Mines of New South Wales on the 21st May, 1885, for a term of nineteen years and two hundred and twenty-five days from that date, that is, up to the end of the year 1905. The number and area of the lands leased are: Block 10, 36 acres; Blocks 11, 12, 13, 14, and 15, 40 acres each; and Block 16, $61\frac{3}{4}$ acres; a total of $297\frac{3}{4}$ acres, representing a length of about 10,000 feet along the general trend of the lode.

Many sensational anecdotes could be told of the early history of the mine, and the men connected with it; but the actual results of the work done will be sufficient to arouse keen interest in its operations.

Of the seven Blocks leased, the Broken Hill Proprietary Company now holds only three, the other four having been sold for no less a sum than £2,320,000, or over £13,000 per acre.

Situated about 26 miles east of the western border of the Colony of New South Wales, and distant by rail about 282 miles from the nearest seaport (Port Pirie, in South Australia), in a country subject to prolonged droughts, there were many difficulties to be

overcome in the early development of the property. It forms the crest of a low range of hills on a plateau about 1,130 feet above sea-level, in the heart of Stanley's Barrier Range; and the country, except after a good rainfall, presents a very barren and uninviting appearance. The Barrier Ranges extend for about 150 miles in a north north-east direction, and vary in width up to 110 miles; they are surrounded by open salt-bush plains, and within them also are numerous similar plains of greater and less extent. Except on the banks of water-courses, trees are scarce; here and there are patches of mulga and acacia, the general herbage of the country, locally known as blue cotton and salt-bush. The soil is fertile, but the absence of moisture absolutely prevents its utilization for agriculture. A partial analysis of the soil, and a table of rainfall for the past seventeen years, are given in Tables II and III, Appendix. It seems to be the rule that rich silver mines are found in dry, barren districts, *e.g.*, Nevada, Arizona, New Mexico, Utah, and Colorado; the barren regions of Old Mexico, and the arid table lands of Chili.

Probably the earliest allusion to the locality of Broken Hill occurs in the year 1844. Captain Charles Sturt, in his "Narrative of an expedition into Central Australia," says:—

"At about 3 miles, we passed a very remarkable and perfectly isolated hill, of about 150 feet in height. It ran longitudinally from south to north for about 350 yards, and was bare of trees and shrubs, with the exception of one or two *casuarinas*. The basis of this hill was a slaty ferruginous rock, and protruding above the ground along the spine of the hill was a line of the finest hepatic iron ore I ever saw; it laid in blocks of various sizes, and of many tons weight piled one upon the other, without a particle of earth either on their faces or between them. Nothing indeed could exceed the clean appearance of these huge masses. On ascending this hill and seating myself on the top of one of them to take bearings, I found that the compass deviated 37° from the north point, nor could I place any dependence on the angles I here took."

The direction of the main outcrop of the Broken Hill lode is about North 48° East. In speaking of the Barrier Ranges, Captain Sturt says: "They are, for the most part, composed of primary, igneous rocks, amongst which there is a general distribution of iron, and perhaps other metals."

Little indeed did Captain Sturt imagine the existence of enormous wealth under an ironstone capping in the desert which he traversed in 1844; and even had he found, as did an aboriginal in 1885, a rich specimen of silver ore, it is doubtful whether anything would have been done at that time to develop the mineral resources of the district. Mining was then unknown in Australia, and the distance from the seaboard, and the uninviting

character of the country would have deterred the most enthusiastic from embarking the necessary capital. The district had been occupied for many years as a sheep-run before attention was directed to it from a mining point of view, and long before the Broken Hill mine was discovered other mines in the neighbourhood had been in active operation. At one of these, the "Day Dream," a considerable quantity of the "Broken Hill" ore was treated before it was thought advisable to erect smelting-works on the property.

It is proposed to deal with the several aspects of the subject under the following heads, tracing the various processes and operations from the mining of the ore to the production of silver and lead bullion, refined silver and soft lead in a marketable form : 1. Geology of the district and description of the ore. 2. Method adopted of mining and sustaining the ground. 3. Shafts, winding- and pumping-plants, etc. 4. Ore reduction works : (a) smelting-plant ; (b) ore-dressing mill ; (c) leaching-plant ; (d) amalgamating mill ; (e) refinery-plant. 5. General surface works : (a) saw-mill ; (b) railway ; (c) electric light ; (d) water-supply and rainfall. 6. Labour—its distribution, cost, and efficiency. 7. Financial and general.

GEOLOGY OF THE DISTRICT AND DESCRIPTION OF THE ORE.

The geological formation consists of metamorphosed clay-slate and talcose mica-schist with intrusive masses and dykes of granite and diorite, which traverse the sedimentary rocks generally in a north-easterly direction, but sometimes in all directions, forming a network of dykes. In places the schists pass into gneiss, which changes into porphyritic granite. The Broken Hill derives its name from the huge masses of black manganese and iron-stained material that form the crest of the hill, which, in spite of its comparatively-speaking insignificant height, forms a conspicuous feature in the landscape, rising about 170 feet at its summit above the adjoining plains, and extending about $3\frac{1}{4}$ miles in length. About a $\frac{1}{4}$ mile to the east, and about the same distance to the west, of the hill are to be seen broad dykes of diorite with quartz veins, and between the diorite and the lode, gneiss, and garnetiferous mica, and talcose schists ; whilst lenticular patches of quartzite and a coarsely crystalline binary granite are of frequent occurrence. The general strike of the rocks is north-west, and they dip about 63° north-west ; but, owing to the crumbling to

which the rocks have been subjected, the direction of the dip is somewhat locally reversed. It has been frequently asserted that this is a true fissure lode, but there is scarcely sufficient evidence to prove this point definitely. The lode, so far as it is known, appears to be a mineralized belt without regular and well-defined walls. There is evidence of the existence of anticlines at various points, and the whole may ultimately be found to come together again beneath, although it is quite as probable that the lode now being worked is only one of a series of "saddle reefs," in several respects similar to that found in the famous and rich mines of Bendigo, Victoria. On the surface the outcrop consists of masses of oxide of manganese, gossan, altered schist, garnet-rock, quartz, and quartzite, with some felspar; rich specimens of iodide, chloride, and chloro-bromide of silver also have been found on the surface in some places. Carbonate of lead did not appear in any quantity at the surface, but underneath both carbonate and phosphate of lead were found in great quantities, containing silver in a variety of combinations. The small quantity of iron pyrites in the mine renders it impossible to account for the presence of the large amount of ferric oxide in the upper portion of the lode by the decomposition of sulphides of iron. The garnet is an aggregate of small crystals of manganese-iron garnet with and without a small quantity of lime.

The bodies of ore exposed may first be classed according to the methods of treatment applicable to them:—(1) Ores suitable for blast-furnace treatment, chiefly carbonate of lead and ferrous oxide, carrying silver; (2) concentrating ores, both oxidized and sulphide, carrying lead and a high percentage of silica; (3) ores containing silver in combination with chlorine and bromine, which, after chloridizing and roasting, are suitable for leaching; (4) ores fit for amalgamation, containing silver as chloride, chloro-bromide, and in the metallic state, associated with a small quantity of lead; (5) argentiferous lead and zinc sulphides requiring concentration. No process is yet in operation for the treatment of the low grade sulphide ores, which exist in enormous quantities below the permanent water-level.

The following list gives a more accurate designation of the principal ores, the results of a more or less complete analysis of which are given in the Appendix, Table I:—(a) Oxides of iron and manganese, containing between 22 ozs. and 160 ozs. of silver per ton. (b) Carbonate of lead, containing between 10 per cent. and 55 per cent. of lead, and between 7 ozs. and 100 ozs. of silver per ton. (c) Kaolin, containing between 12 ozs. and 700 ozs. of silver per

ton, usually metallic or as chloride, iodide, chloro-bromide, or bromide of silver, with or without a small percentage of lead as cerussite. (d) Carbonate and oxide of copper, containing lead in the form of silicate and carbonate with between 30 ozs. and 200 ozs. of silver per ton, frequently associated with massive chloride of silver; native copper is also found in considerable quantities. (e) Garnet rock, being crystals of manganese-iron garnet, carrying between 8 ozs. and 70 ozs. of silver per ton and a small amount of lead. (f) Sulphide ores, chiefly sulphides of lead and zinc with between 7 ozs. and 80 ozs. of silver per ton, and an average of about 30 per cent. of silica and garnet, about 26 per cent. of lead and 21 per cent. of zinc.

The ore-bodies vary much in size, the greatest width yet disclosed being 316 feet and the least 15 feet, the average being about 105 feet. Manganese-iron ore may be said to form the capping of the lode throughout, and the greatest depth to which iron ore may be said to exist exclusively is 300 feet from the surface, although it has been discovered (but not yet proved of any great extent) at 400 feet from the surface. Underneath the iron, the greatest extent of ore exists as carbonate of lead and also as masses of kaolin. Carbonate of copper is found in a horizontal seam within these ore-bodies. Underneath the carbonate of lead and the kaolin lie the enormous bodies of sulphide ore. Plate 2 gives a number of transverse sections of the mine, looking north-east. Figs. 1, Plate 4, show the general disposition of the ore near the sulphide zone as well as a longitudinal section of the mine.

At several points, at varying depths from the surface, the lode is split into two legs by "horses" or masses of barren rock. This important and interesting feature exists more or less continuously throughout the length of the lode, but is more clearly defined towards the southern end in Blocks 11 and 10. Kelly's shaft in Block 10 struck the ore at 380 feet from the surface and entered the "horse" at a depth of 440 feet; at 490 feet ore again made its appearance in the shaft, but passed out of it to the east lower down. The same features exist to some extent at MacGregor's shaft, Plate 1, where the ore-body was struck at 45 feet from the surface; the shaft entered the "horse" at 255 feet, but has not yet been carried any great depth into the rock. The "horse" at McCulloch's shaft does not show the same regularity as that existing at MacGregor's or at Kelly's shafts, being a somewhat irregular mass of barren rock in the form of a diagonal cross-course, breaking the continuity of the lode. Those at Block 14

and the British mines, especially the latter, maintain the characteristics observable at MacGregor's and Kelly's shafts, although the "horses" towards the north are situated at a higher level. At the 400 feet level west cross-cut of the British mine, the "horse" seems to have been cut at about its greatest width, for the stratification, instead of continuing its westerly underlay, is almost vertical. The "horse" at Kelly's shaft is at a greater depth from the surface than at any known point on the line, and has here a more rapid pitch southward than anywhere else. It may be that the lode being like a saddle reef, the legs may terminate at no great depth, and that if any additional deposits of ore are found at greater depths, they may in form be somewhat similar, but not continuous with that now being worked.

It cannot be said that the dip of the ore-bodies maintains anything like a regular direction, for in places the lode stands almost vertical, but, on the whole, the greatest dip is to the west. The average level of the sulphide zone is about 300 feet from the surface; the nearest point to the surface at which sulphides have been found is about 110 feet, whilst the greatest depth at which oxidized ores have yet been found is about 515 feet—a variation of about 405 feet. At some places, thoroughly oxidized and almost pure sulphide ores are found side by side to as great a depth as 200 feet. This may be accounted for on the supposition that the now oxidized ore has been more porous than that remaining as sulphides—thus admitting of the ingress of oxygen—and that the water-level in the mine has varied considerably at different periods. The permanent water-level of the mine is approximately the average level of the sulphide ores, although ore more highly charged with water has been found above the sulphide zones. This can be accounted for as follows:—The oxidized ores are in every place more open and porous than sulphides, and consequently can absorb a greater quantity of water; water finding its way into the lode from the surface would percolate the porous oxidized ores until it reached the permanent water-level of the sulphide ores, and would therefore be retained in the former, owing to the resistance offered to its further progress by the dense nature of the latter. The country has invariably been found dry, and water only occurs in the lode formation. In a neighbouring mine (the Round Hill) a shaft has been sunk through country to a depth of 630 feet almost without water.

The shape of the different ore-bodies cannot be accurately determined until the mine is further developed. This will take some years to accomplish, but it will eventually be precisely mapped

out. The ore-bodies are remarkable for their size and continuity, and, although the values of the silver and lead vary every few feet, still a high average is maintained throughout. Towards the northern end the lead increases and the silver decreases, whilst at the southern end the silver contents are high and the lead contents low. The reason for the oxidized ores being of so much higher a grade than the sulphide may be explained as follows:—The lode and country rock probably reached in the past a much greater altitude than they do to-day, and have, by the operation of natural causes, been gradually reduced to their present limits, and, during this process of denudation, a leaching of the silver has proceeded simultaneously with the oxidation, its action being retarded by a rising, and accelerated by a falling, of the water-level in the mine. It is difficult to account for the enormous deposit of the oxides of iron and manganese, except upon the hypothesis that in the original formation of the lode, probably by thermal or other springs, the greater portion of the iron and manganese gradually accumulated at the surface. The occurrence of enormous bodies of kaolin carrying silver may be accounted for by the decomposition of the mica schist which constitutes the walls of the lode adjoining the kaolin. The pitch of the ore bodies in the strike of the lode is more marked at the southern end than at any other part. Here the pitch is of a rapidly descending grade towards the south. From a little way north of the southern boundary of the Proprietary Company's property to the northern boundary of the British Company's Block 15 (a distance of about 6,600 feet along the lode), the ore-bodies are found generally in a horizontal position. To the north again, the ore-bodies seem to pitch towards the north, and, in the North Broken Hill Company's ground, the main lode appears to thin out.

METHOD ADOPTED OF MINING AND SUSTAINING THE GROUND.

When the mine was in its infancy, and the dimensions of the ore-bodies were undetermined, the method of mining was that usually adopted in small lodes, but in 1887, owing to the great width and friable character of the lode, it was found difficult to maintain the workings and stopes in a safe or satisfactory condition. Mr. W. H. Patton, the general manager at that time, recommended the adoption of what is known as the square-set system of timbering. This system of securing the ground, although costly, and in some respects extravagant, is superior to

that employed previously. It enables larger faces of ore to be exposed and worked at one time, affords more freedom for the men while working, and greater security from accidents. This style of timbering seems to be of German invention, and has been used in various well-known mines in the United States. It is also in use in the following mines at Broken Hill:—The North Junction, British, Block 14, Proprietary, Block 10, Central, and South, but has not yet been introduced into any other mines in Australia. Figs. 2, Plate 4, illustrate the method, and show the scantling of the timber employed. Where the pressure is light, single timbering may suffice; but where heavy pressures exist, false or double sets of timber, with diagonal struts, are used, and, in extreme cases, solid bulkheads of timber have been built to retain the ground. At first the timber was obtained from Australia, New Zealand, and Tasmania, but none of the colonial timbers have proved so suitable as Oregon pine, from Puget Sound, in the United States.

The present regular monthly delivery of timber for the parent company alone at Port Pirie is 1,250,000 superficial feet, sawn to the following sizes, and in the proportionate quantities stated:—

76 to 80 per cent.	10 inches	by	10 inches	,	for forming square sets.
7 to 8	"	10	"	4	" for strengthening square sets.
12 to 17	"	10	"	2	" for flooring and other work.

The timber supplied has been of good quality, and is easily handled and sawn. Other advantages of the square-set timbering are that it enables the value of the weekly output to be maintained with regularity, as, owing to the number of breasts of ore which can be left exposed, ore can be taken from any face, and it affords an excellent means of securing old ground left from previous workings.

It is not to be expected, however, that timbering carried out on the square-set system, or on any other, however well designed and executed, can of itself always withstand the pressures arising from the excavation of such enormous ore-bodies; and filling the stopes at certain points from the hanging- to the foot-wall with hard dry material, such as slag or waste rock, must sooner or later be undertaken, in order to prevent the spread of fire, as well as the collapse of timbers due directly to excessive pressure.

Experts differ as to the advisability of commencing the removal of ore from the foot-wall or hanging-wall side; but, as a question of mining and engineering combined, the Authors have no hesitation in saying that, in a lode of the character and dimensions of

that at Broken Hill, the correct method of opening up the lode and sustaining the hanging-wall, is to commence at the hanging-wall side and carry the timbers up to it—always keeping the base of the timber sets, in cross section, so far advanced towards the foot-wall that the line of timbers on working faces may form a right-angle with the hanging-wall until the foot-wall be reached. At stated points stopes can be carried ahead of the main longitudinal stopes across the lode from the hanging- to the foot-wall, so that the requisite number of different ore-faces may be exposed. In any case, the space from which ore has been removed should be filled with hard dry material as soon as possible. Experience, and very costly experience, has clearly demonstrated that if a systematic opening of such large and continuous ore-bodies be not carried out, serious and dangerous settlement takes place in them, and, in some cases, great masses of country rock become detached from the surrounding rock on the hanging-wall side, and press with enormous force on the ore and timbers underneath. In one case, a mass of country rock, estimated to weigh about 300,000 tons, broke loose from the hanging-wall side, owing to the shrinkage of the timbers and the friable ore underneath. In this instance proper attention had not been paid to securing the hanging-wall, and the ore had been taken out chiefly from the centre and the foot-wall side of the lode, leaving a large mass of friable and easily-compressed ore between the timbers and the hanging-wall.

The quantity of timber required in the framework of one complete set of square-set timbering amounts to 533·4 superficial feet for sill-floor sets, and 405·7 superficial feet for stope-sets; the average total quantity of timber of all sizes, including decking, shoring, lathing, false sets, &c., required per ton of ore removed being about 40 superficial feet (i.e., 12 inches by 1 inch) per ton of ore. The cost of Oregon timber has steadily fallen since it was first introduced for mining purposes, as the following prices show:—

1889, £5 12s. 0d.	per 1,000 superficial feet landed at Port Pirie.
1890, £5 5s. 0d.	" " " "
1891, £5 6s. 0d. to £4 15s. 0d.	" " "
1892, £4 10s. 6d.	" " "

Railway-freight from Port Pirie, including handling, costs about £2 16s., the Customs duty is 15s., and the sawing and preparation amounts to 10s., so that the gross cost of the timber amounts to about £8 11s. 6d. per 1,000 superficial feet, or 6s. 10d. per ton of ore.

The cost of mining per ton of ore by day wages (including

dead work, tramming, and raising the ore to the surface) is as follows :—

	£	s.	d.
Wages	0	17	2
Fuel and stores	0	2	10
Repairs and sundries	0	0	11
Management	0	0	6
Timber	0	6	10
Total	1	8	3

The following Table gives the quantities of ore treated since the opening of the mine :—

Half Year ending	Tons.
November 30, 1885	48
May 31, 1886	1,103
November 30, 1886	10,397
May 31, 1887	18,411
November 30, 1887	28,800
May 31, 1888	39,789
November 30, 1888	54,336
May 31, 1889	68,545
November 30, 1889	88,639
May 31, 1890	103,399
November 30, 1890	103,912
May 31, 1891	138,645
November 30, 1891	147,473
May 31, 1892	180,852
¹ November 30, 1892	73,973
Total for 7 years	1,058,322

Good judgment, skill, and close and continual inspection are required in the mining and timbering; and, although the most experienced and skilful men have been employed to superintend the underground operations, it has been clearly demonstrated that timbering alone is, except in certain places and under certain conditions, quite insufficient to support the enormous masses of ore and the superimposed hanging-wall. Even the use of solid bulkheads of timber of large scantling has been practically valueless; for, although filling the stopes with solid timber has, in certain cases, prevented utter collapse, it has been so costly and has so blocked up the workings, that the extraction of ore at the back of the bulk-heads has been rendered almost impossible, and other means have had to be devised to open

¹ The strike lasted eighteen weeks out of this half-year.

portions of the mine. If, as previously mentioned, the mine had been opened under the hanging-wall first, and the space from which ore had been removed filled with rock, the Authors imagine that little danger would have resulted; but when this style of timbering was introduced, the full extent and character of the ore-bodies had not been accurately determined, and sometimes ore of a certain quality had to be obtained irrespective of systematic mining, in order to enable the output to be maintained.

Not only to relieve the pressure on the timbers, but also to obtain certain qualities of ore more cheaply, the removal of the cap of the lode and quarrying from the surface has been commenced. The depth to which this open-cut work will be carried depends upon circumstances that may arise as the work proceeds; but, so long as it is cheaper and safe, this work will be carried out. The hanging-wall will need to be cut away simultaneously with the quarrying of the ore, and it is estimated that the quarry will thus require the removal of between $2\frac{1}{2}$ and 3 cubic yards of rock for each ton of ore, down to depths between 60 and 100 feet from the surface. A large quantity of timber will also be recovered, which will go to defray the cost of this work.

In order to maintain the hanging-wall below the level of this open-cut work, strong and well-designed walls of waste rock will have to be built from the foot-wall to the hanging-wall. This will cost little, and will practically amount to replacing rock which under any circumstances would have had to be removed. In spite of the serious difficulties which have attended the underground operations, it is most satisfactory to record that no fatal accident has happened to the men employed, which could be attributed to the methods adopted, or to a want of care on the part of those in charge of the operations.

Injury to health, directly attributed to working in the lead stopes of such a mine as this, is still a vexed question. Cases occur where men suffer when working in certain places; but whether the effects are brought about more rapidly by breathing dusty atmosphere, or through an accumulation of dust in the clothing and on the skin, is uncertain. Water in the past has been so scarce that the men could not indulge in bathing, and clothes-washing has had to be reduced to a minimum. The ventilation of the mine is good, and, but for the presence of carbonic anhydride, especially in the carbonate ores, would be excellent. During the latter half of 1888, a system of artificial ventilation by means of fans was introduced, which has enabled drives of considerable length to be made without special air-passes between

the several levels and the surface. The extensive use of compressed-air drills has largely tended to the satisfactory ventilation of the workings. To minimise the raising of lead dust from the friable lead ores, water mains have been laid underground, and the faces and workings are sprinkled at intervals, thus keeping the atmosphere in a fairly satisfactory state, even in the worst portions of the mine.

SHAFTS, WINDING- AND PUMPING-APPLIANCES, ETC.

There are in all eleven shafts, varying between 175 feet and 762 feet in depth, the aggregate length being 4,189 feet. Several of these shafts were started before the dip of the lode had been determined, and are situated without regard to the hanging- or foot-wall; but the more recently sunk shafts are placed on the foot-wall side. The winding-engines vary in design and power, but none of them possess any novelty calling for special remark. On some, flat, and on others, round steel ropes are used, the preference being given to the latter. Three of the shafts are fitted with 9-inch Cornish pumps of ordinary design. It is remarkable that such limited pumping appliances should be more than sufficient to drain a lode of such large dimensions; and it is a great pity that this is the case, for next to the ore itself, there is hardly anything more valuable than an ample and continuous supply of water. The country rock is almost dry, and water is not looked for except in the lode itself.

All the cages are "safety cages," as shown in Figs. 7, Plate 4, and so long as the horizontal steel springs, which work the serrated eccentrics, keep in order, everything is satisfactory. Up to the present time no accident has occurred through failure in these cages, although they have travelled more than 120,000 miles up and down the shafts. They are made entirely on the works. Double cages are not yet used, owing to the comparatively shallow depths of the workings. The signals are communicated in the ordinary way, by means of a cord causing a hammer to strike a gong in the engine-room; and the engine-driver knows the position of the cage by means of an indicator, which in some cases travels on a vertical cylinder geared to the engine, and in others, is of the ordinary vertical type. The winding-, pumping-, and rock-drilling plant, and the mining tools, &c., have cost about £109,635.

ORE-REDUCTION WORKS.

The ore-reduction works comprise :—

(a) *Smelting Plant*.—Blast-furnace smelting has been the principal method adopted in the treatment of the ore up to the present time; this being the most feasible means of obtaining the metal, owing to the high percentage of lead in the bulk of the oxidized ore first discovered at the surface. Lead ores, containing a high percentage of silica, are dressed before being smelted; and the product (or concentrate) forms a first-class smelting material, so far as lead contents are concerned. In June 1886, the entire reduction-plant consisted of two 30-ton Nevada water-jacketed furnaces. Mr. S. R. Wilson, the general manager at that time, wrote to the Board of Directors: "I may safely say we could supply ten furnaces easily with ore, as practically speaking it is unlimited." To-day, the smelting-plant at the mine alone consists of fifteen 80-ton furnaces, of a capacity more than twenty times greater than those on the property in June 1886. Great caution has been exercised by the Directors of the Company in ordering additions to the smelting-plant and reduction works. Shareholders naturally desire to see a maximum quantity of ore treated in a minimum of time, and the Directors have to be satisfied that circumstances warrant any addition to the plant. Experience shows that the most important elements, affecting the increase of ore-reduction works, have been difficulties connected with the water-supply and with skilled labour.

The fifteen furnaces described as of 80-tons capacity, are capable of reducing about 4,500 tons of crude ore per week. The ore, fluxes, and coke are stored in bins behind the smelter-floors; each class of material is first accurately weighed, and is then deposited on the floors, where it is shovelled into the furnace in as regular layers as possible. The slag is wheeled in pots of the form shown in Figs. 6, Plate 4, and deposited to the west of the furnaces. The slag-heaps are now assuming very large dimensions. The blast is supplied by Baker blowers, and varies in pressure—between 8 and 12 ozs. per square inch—according to circumstances. The general design of the furnaces is shown in Figs. 3, 4, and 5. The machinery connected with the fifteen furnaces at the mine consists of :—

One tandem compound condensing engine, with 14-inch and

24-inch cylinders of 30 inches stroke; one pair of horizontal compound surface-condensing engines, with 16½-inch and 26-inch cylinders of 48 inches stroke; one pair of horizontal engines, with a 16½-inch cylinder of 38 inches stroke, with Hartnell expansion-gear. One Westinghouse standard engine with 15½-inch cylinder of 14 inches stroke. Three friction-hoists for raising bullion; eight hydraulic-lifts with 7-inch rams; eleven No. 7½ Baker blowers; one No. 5 Baker blower; three No. 4½ Baker blower; six Lancashire boilers, 7 feet in diameter by 23 feet long; two Cornish boilers, 6 feet in diameter by 25 feet long; Knowles, and Tangye, and Blake feed-pumps.

The total cost of the smelting-plant at the mine has been £120,136. At the refinery, at Port Pirie, the company has an additional 80-ton blast-furnace, which was erected, primarily, for the purpose of re-treating the drosses which accumulate at the works, but which also reduces about 200 tons of crude ore per week.

The Company has practically completed negotiations for the purchase of the British Company's smelting-plant at Port Pirie, which consists of four 80-ton furnaces; so that shortly the smelting-plant at the mine and at Port Pirie combined will consist of twenty 80-ton smelters. All ore, coke and fluxes are conveyed by rail to the various bins. A most important matter connected with smelting-operations, is the supply of good fluxes. Iron flux is at present obtained from the outcrop of the lode and from the quarrying operations. Although there are many ironstone-deposits within a radius of 30 or 40 miles, they are either of only medium quality or of small dimensions; and to obtain this flux, means will have to be adopted of reaching better and larger deposits situated at a greater distance. Iron-ore lodes of exceptional quality are to be found about 70 miles from Broken Hill, and, in one of these, below a depth of 60 feet from the surface, the ore was found to be pure ferric oxide. Limestone is more plentiful in the district than ironstone, and, up to the 11th May, 1891, this flux was obtained from various sedimentary deposits lying between 9 and 12 miles from the mine, at a cost of about 21s. per ton delivered. A large deposit of superior quality was known to exist at Tarrawingee (about 40 miles north-east of Broken Hill); but it was not considered practicable to bring it from this distance, until Mr. J. S. Reid (formerly a director of the Broken Hill Proprietary Company) obtained powers to construct a railway for the purpose. This line, of 3 feet 6 inches gauge, with 41-lb. steel rails, was completed within six months. The Tarra-

wingee limestone is not only remarkably free from insoluble matter; but it is physically of a very superior quality for fluxing purposes. The Tarrowingee Company, in consideration of a contract being entered into for a period of two and a half years, offered the flux at 18s. per ton delivered at the mine, broken to a size not exceeding 4 inches, and averaging not less than 94 per cent. of carbonate of lime. This contract represents a saving to the Broken Hill Proprietary Company of about £30,000 per annum.

Almost all the coke used in the furnaces is obtained from England; for, although there are coke-works in the colonies, very few of the Australian coals make good coke. There is coal in New Zealand from which a good coke can be obtained, and doubtless, before long, a considerable quantity will be made in the colony. The amount of coke used per ton of ore varies, ranging from 17 to 21 per cent. of the total ore (including iron ore obtained from the mine). The percentage of coke rendered valueless for smelting purposes through being broken into fine particles and dust is very considerable. A great portion of it has to be handled four times between Port Pirie and the furnaces. The quality varies both as regards density and purity; and as the cost of the coke is very great by the time it reaches the mine, it is important that only the best quality be obtained; but the various brands (including colonial-made coke) have contained on an average, about 10 per cent. of ash. Coal of fairly good quality is obtained from Newcastle, N.S.W., costing 18s. at Port Pirie; and (including handling) about 44s. 3d. per ton at the mine. The coal contains, on an average, about 29 per cent. of volatile hydrocarbons, 52½ per cent. of fixed carbon, and 12 per cent. of ash.

Although numerous samples of the ore are daily assayed, not only from quantities taken direct from the faces of the stopes, but also from the ore-bins, it would be impossible (unless special sampling-works were erected, and a comprehensive system adopted) to determine with anything like accuracy, the average value of the crude ore before treatment; and there are no reliable means of arriving at losses in smelting, except by an analysis of the slag, which, at the best, affords only a rough indication of part of the losses. It is only in custom-works, where the crude ore is bought at prices ruled by its metallic contents, and the ore is averaged and sampled previous to treatment, that the losses can be ascertained. Matte is not made in any quantity so far, owing to there being abundance of ore comparatively free from sulphur and

suitable for smelting. The following Table gives the ratios of coke and fluxes to ore smelted, and the cost :—

Dates.	Lead Ore.	Iron Ore.	Siliceous Iron Ore and Kaolin.	Coke.	Limestone.	Cost per Ton of Ore.
Half-year ending—	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	s. d.
May, 1888 ¹ . .	48·0	16·0	36·0	21·0	20·0	36 5
May, do. . .	45·0	12·0	43·0	19·0	18·0	32 2
November, do. .	44·8	9·5	45·7	17·0	20·5	35 6
May, 1889 . .	48·5	8·5	43·0	16·8	23·3	33 10
Year ending—						
May, 1890 . .	54·0	8·0	38·0	17·0	27·0	33 9
May, 1891 . .	51·0	9·0	40·0	17·7	35·0	36 10
Half-year ending—						
November, 1891.	52·0	2·0	46·0	18·5	34·0	36 6
May, 1892 . .	51·5	1·5	47·0	18·0	32·0	32 3½

¹ Refers to “small” furnaces; all the remainder refer to “large” furnaces.

The cost includes all expenses from the time the ore is delivered at the smelting-floors, to the delivery of the bullion on the trucks beside the smelters.

The following details of the cost of smelting the ores for the year ending May 1891 will illustrate the different items of expenditure :—

	£	s.	d.
Labour at furnaces, firemen, &c.	0	7	2
Limestone and ironstone purchased	0	8	0
Coke and coal	1	0	7
Superintendence, assaying, stores and water	0	1	1
Cost per ton of crude ore	1	16	10

The total cost of mining, reduction and management, but not including realization charges, amounts to about £3 14s. 1d. per ton.

It must be understood that the above represents the bare cost of the work at and around the furnaces, and does not include any charges for sampling the ore, repairs, renewals, depreciation, freight on bullion, or realization, insurance, desilverizing charges, or any other items chargeable to the bullion after it is put on trucks at the mine, and it takes no account of the losses of silver

and lead. These items are considerable, and vary with the quality of the crude ore, the richness of the bullion, and the cost of coke, fuel, and fluxes.

During the last three years, the cost for labour, engine-drivers, firemen, assaying, and superintendence (but not including cost of sampling) has averaged about 8s. 3d. per ton of ore smelted. The other items which make up the total cost vary with the market value of the material, and the quantities required, as the character of the ore changes.

The bars of silver-lead bullion are regularly put into trucks on the railway which runs behind and adjacent to the furnaces, and travel over the lines of the Silverton Tramway Company and the South Australian Government to Port Pirie (a total distance of 282 miles), where a portion is shipped to England, and the balance is put into the Company's refinery, close to the wharves at Port Pirie. The bullion intended for shipment to England is taken by inter-colonial steamers to Sydney, and there transferred to steamers belonging to the P. and O. Company, the Orient Company, or other lines. The railway charges from the mine to Port Pirie, and the steamer freight to England, *via* Sydney, amount now to 68s. per ton. During the last seven years, 161,599 tons of lead, and 38,822,653 ounces of silver have been produced from 1,058,322 tons of ore, which represents a product of 15·26 per cent. of lead, and 36·68 ounces of silver per ton of crude ore; and the cost of carriage, freight, insurance, and realization amounts to about 12 per cent. of the gross value of the bullion. All the furnaces are built from the designs of Mr. H. H. Schlapp, the company's head metallurgist.

(b) *Ore Dressing Mill.*—This plant was completed in July 1889, and is capable of treating between 150 tons and 200 tons in twenty-four hours. It was erected to treat the lower-grade lead-ores; but, owing to the scarcity of water, it has been found impossible to run the plant continuously, and, up to the 31st May, 1892, it has only treated 98,403 tons of crude ore, and produced about 31,105 tons of concentrates, a ratio of nearly 3·16 tons of ore to 1 ton of concentrates. The total cost of the mill, including engine-power, pumps, machinery, and buildings, has amounted to £39,648. The concentrates, being rich in lead, are a most useful aid to smelting operations; and, although it cannot be said that the operation of concentrating the ores by this plant has been successful, still its enforced stoppage from time to time through want of water has been most unfortunate. Although the concentration of ore is purely a mechanical operation, it presents, in the

case of the ores of Broken Hill, a most complex and difficult problem. Already about £150,000 has been expended on seven concentrating mills in the district, all of them having proved more or less unsuccessful. One of these (that at the British Broken Hill Proprietary Company's mine) has been entirely remodelled, and the results show a great improvement over those obtained in any of the previous mills. There were two principal defects in the larger mills as first erected, viz., improper crushing appliances and an inefficient sizing of the crushed ore. Costly and powerful steam-stamps were employed to crush the ore; but, as the action of these stamps was simply an indiscriminate pounding, the separation of the metallic particles from the gangue particles was very much a matter of chance, and a still more objectionable result was the excessive quantity of slimes (or minute particles) thus produced. The crushed ore left the stamper in particles the sizes of which varied between such as would just pass through a screen with holes $\frac{1}{8}$ inch by $\frac{1}{2}$ inch, to particles of the most minute size; and at this point existed the second defect mentioned. Instead of screening these varying-sized particles according to their dimensions, an appliance called an "hydraulic separator" was used, which to a great extent roughly separated the particles according to weight; with the result that the jigs, which depend for their successful action upon having particles to treat of nearly equal size, but of different weights, had to treat particles of nearly equal weight but of different sizes. This condition of matters rendered the jigs incapable of doing good work. The following details connected with the plant may prove interesting, although it cannot be considered that this class of machinery will prove successful for the concentration of a similar lead ore; still, for treating an ore the metal of which is in native form, such as metallic copper, and which will not slime readily, it might prove satisfactory.

The crude ore is first of all tipped on grizzlies (i.e., stationary screens of bar iron, with spaces $\frac{3}{4}$ inch wide between the bars). Some of the ore passes through these screens to revolving screens, the remainder going directly to the steam stamp. The revolving screens are $6\frac{1}{2}$ feet long, 2 feet in diameter at the inlet, and 3 feet in diameter at the outlet, with holes $\frac{3}{8}$ inch in diameter and $\frac{3}{4}$ inch from centre to centre. These screens make 17 revolutions per minute, and serve the purpose of separating the more finely divided particles from the material which passed through the grizzlies; the ore which cannot pass through the meshes of the revolving screens, being discharged through the

lower end, goes, along with the other larger pieces of ore, to the steam-stamp. The steam-stamp (made by Messrs. Fraser and Chalmers, of Chicago) is capable of reducing about 120 tons in twenty-four hours, and acts somewhat similarly to a steam-hammer. The stem and shoe, which are made of chilled iron, weigh together $1\frac{1}{2}$ ton; the working drop is 24 inches, and the stamp makes 91 strokes and 30 revolutions per minute. The crushed ore passes through a screen of $11\frac{1}{2}$ feet area, with holes $\frac{1}{8}$ inch by $\frac{1}{2}$ inch, spaced $\frac{3}{4}$ inch from centre to centre. The weight of this steam-stamp is 60 tons. As before pointed out, it is a most unsuitable machine for the work it is intended to do, and in two of the mills it has been removed to make room for stone-breakers and plain-faced rolls. The fine-screened and crushed ore is then carried by water along the hydraulic classifier, which is simply a long inclined iron trough furnished with spigots, the outlets of which can be regulated as desired to the various jigs. The jigs are of the well-known "Collom" type, and are not worthy of special description. There are sixteen double jigs of two compartments, with pistons making one hundred and twenty strokes per minute and twelve double jigs of three compartments, with pistons making one hundred and thirty strokes per minute. The fine particles (or slimes) are conveyed to revolving tables, of which there are five. These tables are 19 feet in diameter, and have a slope from the centre of $1\frac{1}{8}$ inch to a foot, and revolve once in two minutes. The slimes are fed continuously at the centre, and flow over the surface of the tables towards their periphery in one direction. They are acted upon by fine jets of water, which carry off the lighter and less valuable portion, leaving the heavier portion in concentric rings on the surface of the table, and, at a little distance behind the fine jets, a stronger stream carries the heavier particles into a trough—the table being, as it passes round again, ready to receive slimes from the centre.

The quantity of water required to keep the mill at work is about 1,647,000 gallons in twenty-four hours, but the greater portion of this water is used over and over again, and the net loss of water by evaporation and absorption amounts to about 30,000 gallons in twenty-four hours—equal to about 176 gallons per ton of crude ore. The silver being frequently present in the oxidized ore, dissociated from the lead and associated as chloride of silver with minute particles of silica, the successful concentration of a great quantity of the ores at Broken Hill is impossible. Hence it is that, although the concentrating-mill may recover a fair percentage of the lead, a large quantity of the silver contents

of the ore remains in the tailings. These tailings, when sufficiently rich in silver, are sent to the leaching-plant. The cost of dressing the ore by this mill (including labour, superintendence, steam and water) amounts to about 10s. 6d. per ton of crude ore.

(c) *Leaching-Plant*.—This plant was completed in June 1890, at a cost of about £15,104, and was designed to treat the tailings of the concentrating-mill, as well as some kaolin and siliceous iron ore, which exist in large quantities and which are unsuitable for smelting. Experimental tests were made which seemed to point to leaching as a successful method of treatment, and on the results of these experiments the present plant was erected. It was designed to treat about 2,800 tons of material per week, and comprised: twelve lixiviation-vats, 16 feet in diameter by 7 feet deep; twelve precipitation-vats, 10 feet in diameter by 9 feet deep; four storage-vats, 10 feet in diameter by 9 feet deep; as well as a special laboratory and all the appliances required for a first-class lixiviation plant.

Hyposulphite of sodium solution, between $\frac{3}{4}$ and $1\frac{1}{2}$ per cent. strength, has been tried, with and without addition of bluestone, but the results have not proved so successful on a large scale as the original experiments foreshadowed. The silver in the tailings is mainly in the form of silver chloride, chloro-bromide and iodide, and native silver. The mechanical condition of the ore is unsuited for successful leaching, for it may occur that a fine particle of chloride of silver is partially or wholly enveloped with silica or other protecting substance, thus preventing the leaching fluid from reaching the silver compound; and if, to avoid this, the ore were crushed fine, it would, when placed in large vats, become so compact that the fluid would not pass through. Experiments have been conducted with a view to convert the iodide and native silver into an artificial chloride by a chloridizing-roasting with common salt, as it is well known that an artificial chloride leaches readily. These experiments showed that a great improvement could be made, and works consisting of a "Howell" chloridizing- and roasting-furnace are now in progress of erection capable of treating between 35 tons and 45 tons per day, according to the character of the ore. Should this addition to the leaching-plant prove successful, enough chloridizing-roasting furnaces will be erected to keep the entire leaching-plant at work. Up to the 31st of May, 1892, 40,794 tons of concentrator tailings and crude ore had been treated by this plant, producing 304,798 ounces of silver, at a cost of about 6s. 1d. per ton. The plant has not yet been worked to its full capacity, which cannot be done until

the chloridizing-furnaces are complete. The total cost of crushing, chloridizing, roasting and leaching, will amount to about 20s. per ton.

(d) *Amalgamating-Mill*.—As the mining of dry kaolin and siliceous ores have for some time past far exceeded in extent the discovery of new bodies of lead ore, it has become necessary to adopt some means of economically treating these dry ores. Pan-amalgamation was thought to be the most suitable process, and, to test the matter thoroughly, a full-sized set of pans was erected, and kept constantly at work on the various dry ores for a period of six weeks. The results of these tests proving satisfactory, as regards efficiency and cost, it was decided to erect a 60-stamp mill, with grinding-, amalgamating-, and settling-pans. This mill is now nearing completion, and, if it prove satisfactory, it is the intention of the Company to greatly extend this system of ore-reduction. The mill, as now being erected, is estimated to treat about 200 tons per day. Each stamp (with its stem) will weigh 850 lbs., the diameter of the shoe being $8\frac{1}{2}$ inches, and the stamps are designed to give ninety-five $6\frac{1}{2}$ -inch blows per minute. The twenty-four grinding- and the twenty-four amalgamating-pans are of cast-iron, 4 feet 6 inches in diameter by 3 feet 4 inches deep, the former being designed to run at 40 revolutions and the latter at 80 revolutions per minute. The twelve settling-pans have cast-iron bottoms and wrought-iron sides, and are 8 feet in diameter by 3 feet 6 inches in height, to run at 14 revolutions per minute. The dies of the grinding- and amalgamating-pans are of white cast-iron, 3 feet $7\frac{1}{2}$ inches in diameter and $2\frac{1}{2}$ inches thick, and the mullers are also of white cast-iron, with three radial openings and three lugs. Each pan has eight cast-iron mould-boards. The engine has two cylinders of 20 inches diameter with a 48-inch stroke, and is fitted with Proell valve-gear. It is expected to indicate 400 HP.

The estimated cost of the mill is £50,000; and, from the test made, it is believed that the ore can be treated and the silver obtained of about $\frac{7}{1000}$ fine, at a cost of about 12s. per ton of ore. Water, which has already been employed in the leaching-plant, will be available for use in the amalgamating-mill.

(e) *Refinery Plant*.—The refinery is situated at Port Pirie, the port at which all supplies for the mine are received, and from which the bullion is shipped away. The plant, designed by Mr. H. H. Schlapp, was completely erected in December 1889, and has cost £22,489. The process employed is generally known as the "zinc" process, which was invented in 1850 by Mr. Alexander Parkes, of

Birmingham; but has since been greatly improved. The method is based upon the fact that molten zinc has a strong affinity for gold and silver, and will, under favourable conditions, unite with them and form an alloy. The zinc being readily separated from the gold and silver by distillation, the process affords a ready method of separating these metals from the lead.

The product from the mine, technically known as silver-lead bullion, is delivered at the refinery as rich in silver as possible. The marketable products of the refinery are soft lead of excellent commercial quality; silver from $\frac{999}{1000}$ to $\frac{9999}{10000}$ fine; and doré silver (or gold-and-silver bullion). When copper, antimony and arsenic are present in large quantities, by-products requiring re-treatment are produced. This re-treatment is effected in reverberatory- and ordinary blast-furnaces, along with crude ore, the products being lead-bullion, copper-matte, and antimonial lead. The general outlines of the process are:—(1) Liquefaction, by which an easily-fusible metal is made to separate from one less fusible; (2) Chemical changes—in which the impurities in the silver-lead bullion are converted into compounds which are lighter than the lead and silver, and therefore rise to the surface of the molten metals as scum, being thus easily removed. The final separation of the last portion of the lead from the silver is effected by cupellation and the last of the impurities (zinc, antimony, &c.) from the lead by steam in refining the lead; (3) Chemical affinity—by which zinc combines with the whole of the gold and the silver contained in the lead; the alloy thus formed having a lower specific gravity and requiring a higher temperature for its fusion, rises to the surface when the heat decreases, and is then skimmed off.

The plant consists of two 20-ton softening-furnaces, four 20-ton desilverizing-kettles, four 20-ton lead refining kettles, two liquefaction furnaces, sixteen retort-furnaces, and a blast-furnace. The plant is capable of treating between 400 tons and 500 tons of silver-lead bullion per week, the quantity depending upon the purity of the material; for, if antimony and arsenic are present in large quantities, the operation of refining is delayed. The products from the refinery are disposed of as follows:—

The pure silver is sold in the colonies by tender at stated intervals, in parcels of between 100,000 ozs., and 150,000 ozs., and is purchased by the banks, usually at a price somewhat above the price current in London. The soft lead is shipped either to England or to China; the latter country is becoming, gradually, a larger buyer of the Company's lead. The matte and other compound products are shipped to England. The small amount

of gold in the ore is recovered in the refinery. It amounts to about 3·4 dwt. per ton of bullion.

The average cost of desilverizing is from £1 15s. to £2 per ton of bullion; but, as will be readily understood, the cost of treatment varies considerably as the bullion is rich, or otherwise, in silver, or contains a high or low percentage of impurities requiring re-treatment. The working losses amount to about 4 per cent. lead and 2 ozs. silver per ton of bullion. The number of men employed is about eighty. The refinery and smelting-plant at Port Pirie are under the superintendence of Mr. Gregory Board.

GENERAL SURFACE WORKS.

Saw Mill.—The entire preparation of the timber for the mine, including handling, sawing, fitting and stacking, is done by contract, at a cost of 10s. per 1,000 superficial feet. The saw mill and appliances are the property of the Company; but the contractor has to keep them in repair, find all saws, labour and incidental requirements. The plant is so arranged that the timber is cut and dressed to the exact size required with as little handling as possible, and comprises the following machines:—Swing cross-cut saw, 48 inches in diameter, for sawing timbers to the required length; Angle-saw, 36 inches in diameter, for preparing the ends of diagonal struts; Square-set saws, 18 inches in diameter, placed so that, in one operation, the checks in the caps and legs can be sawn on two sides; Rip-saw 48 inches in diameter, for sawing driving-laths, &c.; Firewood saw, for rough work; Planing-machine, for finishing shaft-guides and other finer work.

Railway.—Broken Hill is most awkwardly situated with reference to the railway system of New South Wales. The nearest and most natural route between it and the sea-board is in a south-westerly direction, into South Australia. Had the mine depended upon the Government of New South Wales constructing a means of communication, it is certain that it would not have enjoyed railway facilities for years after its discovery; and it is probable that to-day the mines would, on that account, have been only of second-rate importance.

It fell to the lot of private enterprise to supply the want within the colony of New South Wales, and the line known as the Silvertown Tramway was constructed, being completed on the 11th January, 1888. This line diverted the traffic from New South Wales into South Australia, the latter colony having at the time

constructed a line as far as Cockburn, on its Eastern border—virtually trusting to teams and ordinary cart-traffic to keep the line at work. The length of the line constructed by the Government of South Australia from Petersburg to Cockburn, in order to obtain the trade and traffic of Broken Hill, was 145 miles. The South Australian Government made their extension from Petersburg to Cockburn of 3 feet 6 inches gauge, and the same gauge was continued by the Silverton Tramway, and by the mines through and along the various properties from the termination of the Silverton Tramways Company's line.

The older, and many of the main lines of railway in South Australia are of 5 feet 3 inches gauge, the remainder being of 3 feet 6 inches. All the lines in New South Wales are of 4 feet 8½ inches gauge. It would have been unreasonable to expect the Government of New South Wales to construct a railway on the route of the Silverton Tramway which absolutely diverts the traffic away from their colony; and, at the time of the construction of the Silverton Tramway, there was nothing to warrant the construction of a 4 feet 8½ inches gauge line from Nyngan, the nearest point on any existing line, a distance of 358 miles, and a total of 735 miles from Sydney. The length of the Silverton Tramway is 35 miles, and the steepest gradient towards Broken Hill is 1 in 80, and the total cost of construction, including sheds, houses for men, workshops and plant, but exclusive of rolling-stock, has amounted to £223,000. The traffic between the terminal points is, however, conducted by the Government of South Australia, at the rate of 3s. 2d. per train-mile, which, under the circumstances, yields a handsome profit to the Railway Department, the loads being limited to 150 tons of goods per train. It is conducted and managed in a most able manner, and, without it, Broken Hill would be far behind its present position in point of population and general importance, for it is now the second town in New South Wales. The Government is now constructing a railway from Nyngan to Cobar, a distance of 81 miles, and the distance of the latter place from Broken Hill is 277 miles; but it is extremely doubtful whether a profit could be earned on a line from Broken Hill to Sydney, a distance of 735 miles.

Electric Light.—The surface-works of the Broken Hill Proprietary Company's mine have been partially lit by electricity for some time past, and recently the whole of the lighting has been re-organized and considerably extended, the present installation embracing the whole of the surface-works, with the private houses of the general manager and mine officers,

the offices of the Company, and a portion of the underground workings in the vicinity of the several shafts. The extreme distance over which the lighting now extends is from a point $\frac{3}{4}$ mile to the north of the generating-station to the same distance south of it. The underground lighting extends to a depth of 500 feet below the surface.

The generating-station is situated on the North Slag Dump, the main building, 70 feet by 38 feet, being of galvanized iron, lined and floored with special provision to exclude the dust, which is so prevalent in the summer months. Attached to the main building is a smaller one, 30 feet by 12 feet, comprising an electric-testing room, a workshop for small repairs, and the electric superintendent's office. The generating-plant consists of 3 steam-engines, (supplied with steam from a bank of 5 Lancashire boilers, situated 100 feet from the building), connected by belts with three sections of counter-shaft and 6 dynamo-electric machines. The whole of the driving arrangements are rendered interchangeable by clutch-couplings between the sections of the counter-shaft, and similar gear on the main pulleys. The plant, which is divided into three sets, comprises the following machinery:—(1) A Thompson single-cylinder horizontal engine, 12-inch cylinder, with 2 feet stroke, running at 110 revolutions per minute. This engine is fitted with Thompson automatic quick cut-off valve-gear, and drives, by a 16-inch india-rubber belt, one section of $3\frac{1}{2}$ -inch countershaft 10 feet long, and a Crompton compound dynamo of 110 volts and 220 amperes capacity, at 840 revolutions per minute; (2) A Tangye single-cylinder horizontal engine, 18-inch cylinder, 3 feet stroke, running at 82 revolutions per minute. This drives, by means of a 16-inch leather belt, a section of countershaft and two dynamos similar to those mentioned above; (3) A Robey single-cylinder horizontal engine, 10-inch cylinder, 20-inch stroke, running at 120 revolutions per minute. This engine drives, by means of a 12-inch india-rubber belt, a similar section of countershaft and two Crompton compound dynamos, each of 110 volts and 45 amperes capacity, at 680 revolutions per minute.

From the several machines, the cables are carried above the ceiling to a general switch-board, where all the circuits are controlled, and the pressure and current indicated by suitable instruments. The switch-board is of slate, handsomely mounted, and contains main switches for five night- and three day-circuits, and one arc-light circuit. From the generating-station the current is conveyed by overhead insulated cables hung on posts by

strained iron wires and insulators. Safety cut-outs are fixed on both mains at every junction of branch-wires with a main or sub-main, and the necessary switches are provided. The wiring of interiors is carried on insulators or in casing, according to position, the wiring underground being all enclosed in wrought-iron piping. The outdoor and underground lights are enclosed in water-tight guarded fittings; indoor lamps are mounted with reflectors or shades to suit their position, and the lamps in private houses are mounted on fittings that match the decoration. At present 700 incandescent lamps and 20 arc-lamps are in use throughout the mine. One set of generating-plant supplies the whole of these, the duplicate set being kept in reserve. The third (smaller) set supplies the underground lights during the hours of daylight, one of the dynamos in this set being sufficient for this purpose, and the other being kept in reserve. All the dynamos are provided with duplicate armatures, as a further precaution against breakdowns. The arc-lights are of 2,000 candle-power each, and the incandescent lamps of 8, 16, and 32 candle-power, according to requirements.

In the electric-testing room a terminal-board has connections with every circuit, and weekly tests are made of the insulation in the lines. In this room also photometric apparatus is being provided to compare the candle-powers of lamps. The arc-circuit has also terminals here, to permit the introduction of lamps for adjustment. A record is kept of insulation-tests, and an hourly record of the load on the dynamos throughout the year. All the lamp-stations are numbered, and the renewals entered, in order to compare the actual performance of the lamps. The insulation of the whole is maintained at 500,000 ohms between the lines and earth. A rapid extension of the lighting is always in progress, owing to the erection of new works and additions to existing ones, and the installation has been designed with a view to meet these extensions. The machinery works night and day, and, up to the present time (since the new installation has been brought into working order), no stoppage has occurred. A considerable reduction in the cost of maintenance will shortly be effected by the introduction of storage-batteries to supply lights during the day.

Water-Supply and Rainfall.—In addition to the water obtained from the underground workings as the shafts were sunk, and the ore-bodies tapped, rain-water is stored on the surface in large excavated tanks. Although, by very eminent authority, the Directors were led to believe that as the ore-bodies were broken into at successive depths the yield of water would increase, the reverse has so far proved to be the case; but it is possible

that as greater depths are reached the water in the ore-bodies may increase. Water obtained in the surface-tanks is, as may well be imagined, an uncertain source of supply, and to be obtained only after exceptionally heavy falls of rain; and evaporation, especially in shallow reservoirs of small area, is very great. The surface-tanks are situated about a mile from the works, and are capable of holding 18,000,000 gallons, the water being pumped through a 6-inch cast-iron pipe to tanks on the mine, situated in positions for distribution to the various plants. Mine-water alone is unsuitable for use in the boilers or in the jackets of the furnaces, owing to the presence of lime and magnesia; and at times serious delays, and serious damage, have resulted from this cause when only mine-water was available. Another most valuable source of supply has been brought into use—one which in the past had been overlooked by graziers as well as mine-owners—viz., the limestone deposits from which the greater part of lime flux had, previous to the opening of the Tarrawingee Quarry, been obtained, which was known to contain water about 12 feet below the surface. These beds of limestone are of considerable area, and their depth is as yet unknown. During a period of water-famine the Proprietary Company brought water in trucks along the Silverton Tramway, pumping the water from the limestone deposits into an elevated tank alongside the railway, from which it was delivered into water-trucks, and thence to the mine, a distance of about 9 miles. This method was continued for some time, and the slight effect observed in lowering the water in the limestone led to a permanent pumping-plant and a line of 6-inch pipes being laid down to the mine. The four Proprietary Companies formed a "Water Trust" to defray the cost of the work, and the quantity of water used by each Company is registered by means of Siemens meters. The total cost of this work has been about £23,000; and the erection of the pumps and boilers, and the laying of 10½ miles of 6-inch pipe were completed within 90 days from the date of starting operations, and would have been accomplished in a shorter time, had difficulties in obtaining the pipes not arisen. The charge for the water is 7s. 6d. per 1,000 gallons, being fixed at this high rate largely on account of the uncertainty of its lasting any great length of time, and in order that the capital expended may be returned to the Companies in three years. The actual net cost of delivery is about 3s. 1d. per 1,000 gallons, and the quantity delivered averages 70,000 gallons per day; the total quantity pumped to date amounting to 27,253,000 gallons. Several independent water-schemes have from time to time been formulated,

and for two of these Acts have been obtained from the New South Wales Parliament; but in only one case has any substantial attempt been made to supply this most essential want. One of these Acts empowered a Company to take water from the River Darling, a distance of 60 miles from Broken Hill, at a point more than 800 feet below the mines; but as two years were allowed by the Act for the completion of the work, and at the expiration of that time no attempt whatever had been made to execute it, the Act lapsed.

The other scheme (that of the Broken Hill Water-Supply, Limited) was sanctioned after long and bitter opposition from the residents of Broken Hill and in Parliament; and powers were obtained to construct works to bring water from Stephen's Creek, a distance of about 10 miles north from Broken Hill. This Company has vigorously carried out its work, having expended £180,000, the works being originally designed by Mr. George Gordon and Mr. J. D. Derry, M.M. Inst. C.E.; the consulting engineer was Mr. Oswald Brown, M. Inst. C.E.; Mr. C. Jobson, Assoc. M. Inst. C.E., acting as Resident Engineer. Stephen's Creek is a typical Australian creek, and only contains water after heavy rain, and never actually discharges water from its middle and upper reaches into the River Darling, of which it is supposed to form a tributary. The catchment-area is about 170 square miles, and consists chiefly of hilly country, which will facilitate the rapid accumulation of water in Stephen's Creek during a heavy fall of rain. The capacity of the reservoir is 3,940,000,000 gallons. The loss by evaporation will be considerable, but the reservoir accommodation is good, and the embankment and weirs are of a most substantial character. The works consist generally of an earthen embankment across the creek, with concrete weirs at each end, situated at a point where the hills abut abruptly on the banks of the creek. The embankment is 440 feet in length, 35 feet in height, and the breadth of the base averages about 225 feet. The weirs are respectively 215 feet and 165 feet long. The pumps, manufactured by the Austral Otis Engineering Company, Melbourne, are of the triple-expansion duplex horizontal type, supplied with steam from Babcock & Willcox boilers, and are capable of delivering 1,250,000 gallons in twenty-four hours to the service-reservoir at Broken Hill, a distance of 10 miles, the lift being 377 feet.¹

¹ The reservoir at Stephen's Creek has since become about one-fifth filled and contains about 800,000,000 gallons.

These works afford a striking exhibition of the determination to procure a supply of water at any cost; and, although the works in themselves are well designed and executed, the uncertainty of the supply has further induced the Company to apply to the Parliament of New South Wales for an Amending Act, to empower them to pump water from Lake Speculation (near the River Darling) to the reservoir at Stephen's Creek. The estimated cost of the additional steel mains and pumping-plant is £150,000. The distance of Lake Speculation from the reservoir at Stephen's Creek is about 50 miles, and the lake is about 400 feet below the level of the reservoir. Lake Speculation does not depend upon local rainfall, being filled from the River Darling during high floods. This occurs only once every two or three years; but the quantity of water which can be retained in the lake is very great.

The rainfall at Broken Hill, Appendix, Table III, is small, and for months together no rain falls. May is the month during which most rain has fallen; but no reliance can be placed on the occurrence of rain at a particular season. The smallest annual fall of rain known is 3·26 inches, and the greatest 16·15 inches.

To the east and south of the Barrier Ranges (28 to 36 miles from Broken Hill) there is a large expanse of Tertiary strata, within which it is believed that a permanent supply of fresh water could be obtained by deep boring. In this area wells have been sunk, in some of which fresh, and in others brackish, water has been met with; but in no case has the sinking been deep enough to show whether the Cretaceous formation occurs underneath the Tertiary.

LABOUR.

The following Table gives the number of persons employed on the mine at different dates.

	Men and Boys.
Half-year ending—	
30 November, 1886	375
31 May, 1887	664
30 November, 1887	898
31 May, 1888	1,231
30 November, 1888	1,666
31 May, 1889	2,127
Year ending—	
31 May, 1890	2,309
31 May, 1891	2,545
Half-year ending—	
30 November, 1891	2,638
31 May, 1892	3,203

In addition to these, about one hundred and forty-four men are employed by the Company at the Refinery and wharves at Port Pirie. The men breaking and raising ore underground, fixing timbers, shaft-sinking, and performing other mining operations, including gangers and foremen, represent slightly more than one-half the total number of men engaged at the mine.

Eight hours is the recognized period of work for all classes of workmen; overtime is of very exceptional occurrence, and is discountenanced alike by the masters and the men. Wages are high, as may be seen from the following Table of the daily rates paid :—

	s.	d.	s.	d.
Mechanics	11	0	to	12 0
Masons, bricklayers, carpenters, blacksmiths, and fitters	10	0	„	12 0
Boiler-makers	12	0		
Engine-drivers (winding)	10	0	„	11 0
Machine-men and riveters	9	0	„	10 0
Engine-drivers (stationary), tin-smiths, miners, tappers, feeders at furnaces, shift washers, and engine-drivers at concentrating-mills	10	0		
Firemen, brace- and plat-men, charge and slag-wheelers, and runners, and feeders at concentrating-mills	9	0		
Saw-mill hands	8	4	„	10 0
Blacksmiths' strikers, assistant firemen, horse-drivers, truckers, and all labourers	8	4		
Boys	3	0	„	7 6

Overtime is paid at the rate of time-and-a-quarter.

Among the many different classes of workmen employed, it cannot be said that any one class of labour is highly skilled, although among each class there are individual workmen who are superior and skilful. But, on the whole, the efficiency of the workmen is not high, and certainly not in relation to the wages paid.

Unionism at Broken Hill has been directed not towards raising the qualifications of the workmen, but to maintaining high wages and the performance of a minimum amount of work; and an inferior workman has to be paid at the same rate as a skilful and energetic man—at least such is the outcome of unionism as practised at Broken Hill. In spite of the good wages paid, difficulty is experienced in obtaining efficient labour; and, in the words of Mr. W. Harper (Mining Manager)—“Though numerous applications for employment are made by men representing themselves to be efficient miners, the difficulty in obtaining first-class

men for skilled underground work still exists." It is to be deeply regretted that unionism, which in principle is unobjectionable, should have the unfortunate result of dulling the energies and ambition of active and intelligent workmen, and raising the emoluments of the lazy and indifferent.

Labour troubles have not been frequent or serious since the commencement of operations. A generally conciliatory spirit has throughout been shown by the Directors of the Associated Mines in every dispute; and, in consequence, harmonious relations are preserved between the men and the management. Since November, 1889, Unionism has been recognized by the Directors, and no man is employed unless he is a member of some Union.¹

FINANCIAL AND GENERAL.

Many metallurgical and engineering questions of vast importance still remain to be solved, and on their successful elucidation rests the permanence and prosperity of the field for many years to come. The sulphide ore, the treatment of which is the great

¹ Since the above was written a great and important change has come about in connection with the employment of labour at Broken Hill. The tyranny of the labour leaders became more and more unbearable, and the men (especially underground) were rapidly becoming demoralized, doing as little work as they possibly could. Under Union rules stoping of ore by contract was not permitted. The management, being brought face to face with a constantly declining price for silver and lead and an exorbitant outlay for the breaking and raising of the ore, asked the men, through their leaders, to agree to stop ore by contract. The leaders did not consult the men on the matter, and would not meet the wishes of the management. One month's notice was therefore given to the Unions, terminating the old agreement under which Unionism was recognized, and the Directors of the Associated Mines stated boldly that they intended in future to work the mines only under "freedom of contract." The men immediately struck, and their leaders refused to declare the strike off until it was too late for a great many of the old hands to get work, their places having been filled by men from the other colonies. Many acts of violence and cowardice were perpetrated by Union men and women on the men who returned to work; but the calm firmness displayed by the Government of New South Wales, and the courage of the few mine officers who remained at their posts, prevented matters reaching an extreme crisis. In fairness to the industrious workmen it must be said that the strike was distasteful to them, and only intimidation prevented them from returning to work earlier. The men now engaged underground stoping ore by contract are making better wages, and giving better value for the money they receive than under the old system. The strike lasted eighteen weeks, and threw fully five thousand men out of employment. No attempt was made at any time by the employers to reduce wages or curtail the just rights of the men.

problem, contains metals of the value of about £7 7s. 3d. per ton; and it will be strange indeed if this is not at an early date turned to good account. Professor Schnabel, the metallurgist, remained for some time on the field conducting experiments on the sulphide ore, having been engaged by the Mine Owners Association of the district to devise an economical means for the treatment of this class of ore.

The following Table is of interest, as showing the quantities of silver and lead produced from the principal mines on the main line of lode, and dividends paid :—

PRODUCTION OF METALS, AND DIVIDENDS PAID.¹

Name of Company.	Silver.	Lead.	Dividends Paid.
	Ozs.	Tons.	£.
Broken Hill Proprietary Co. . .	36,512,445	151,945	3,896,000
" " Block 10 . . .	4,887,958	1,290	485,000
" " Block 14 . . .	4,186,260	42,655	225,000
" " British . . .	1,192,689	18,241	nil
Central Broken Hill . . .	3,167,507	7,765	105,000
Broken Hill Junction . . .	1,061,379	4,258	10,000
" " South . . .	1,043,398	3,181	nil
" " North . . .	319,043	1,786	nil
Totals . . .	52,370,679	231,121	4,721,000

In addition to the above eight mines, there are many others at work on what are considered to be the likely situations on the main lode; but no others have as yet found any ore of profitable quality.

The continued fall in the price of silver and the low price of lead causes considerable anxiety to all interested in silver-lead mining. The prices of these metals, as far as the producer is concerned, will in all probability conform to the variations in the ratio of the supply to the demand. Even taking the value of the lead towards reducing the cost of obtaining the silver, some mines can barely pay their way with silver at 3s. 3d. per ounce standard.

¹ This Table gives the production up to May 31st, 1892. The strike took place on July 3rd, and ended on November 7th; but during the six months ending November 30th, the parent Company, notwithstanding the strike, treated 73,973 tons of ore, producing 2,310,208 ozs. of silver and 9,653 tons of lead, and paid one dividend of £96,000, besides paying £43,759 for additional plant.

The following are the highest and lowest prices received for the Company's silver and lead.

—	Highest.	Lowest.	Remarks.
Silver	{ 4s. 7d. Sept., 1890	{ 3s. 17d. Aug., 1892	} Per standard ounce.
Lead	{ £15 10s. Dec., 1887	{ £10 1s. 3d. Nov., 1892	} Per ton without silver.

The total cost (including capital expenditure, such as plant and development work) of producing and disposing of the silver and lead for the half year ending 31st May, 1892, has been about 2s. 3d. per ounce of silver, and £7 10s. per ton of lead. But by allowing the profit on the lead to go in reduction of the cost of the silver, the net cost of producing the silver is about 1s. 10½d. per ounce.

The Paper is accompanied by twelve sheets of drawings, from a selection of which Plates 3 and 4 have been prepared.

APPENDIX.

COMPOSITION OF ORES.

TABLE I.—1. IRON ORE.

	Per cent.		Per cent.
Pb	9.0	Al ₂ O ₃	4.5
SiO ₂	34.0	ZnO	5.5
FeO	34.0	CaO	3.0
MnO	9.5	Silver	22 to 160 ozs. per ton.

2. CARBONATE OF LEAD ORE.

	Per cent.		Per cent.
Pb	35.0	Zn	4.2
SiO ₂	32.0	CaO	2.1
MnO	3.5	S	2.0
FeO	7.3	CO ₂	9.5
Al ₂ O ₃	3.8	Silver	7 to 100 ozs. per ton.

3. KAOLIN.

	Per cent.		Per cent.
Pb	9.0	Al ₂ O ₃	13.0
SiO ₂	49.0	CaO	2.8
FeO	14.0	CO ₂	2.0
MnO	9.5	Silver	12 to 700 ozs. per ton.

4. GARNET ROCK.

	Per cent.		Per cent.
Pb	1.5	MgO	1.4
SiO ₂	34.0	CaO	trace
FeO	21.0	S	trace
MnO	27.0	Silver	from 8 to 70 ozs. per ton.
Al ₂ O ₃	15.0		

5. SULPHIDE ORE.

	Per cent.		Per cent.
Pb	27.5	CaO	trace
SiO ₂	20.0	S	19.7
FeO	7.5	As	0.4
MnO	1.0	Silver	from 7 to 80 ozs. per ton.
Zn	23.0		

Results of assays of sulphide ores are given on Plate II.

TABLE II.—ANALYSIS OF SOIL.

The soils are very ferruginous; the amount and nature of the soluble salts was in analysis chiefly attended to.

Numbers	1	2	3	4	5
Reaction	Per cent. alkaline	Per cent. alkaline	Per cent. alkaline	Per cent. neutral	Per cent. neutral
Sulphuric acid combined, SO ₃	0·027	0·188	0·082	0·061	0·068
Chlorides as chlorine	0·039	1·93	0·177	0·177	1·020

Nos. 2 and 5 contain a large proportion of sulphates and chlorides. The soils are rich in oxides of iron and comparatively free from organic matter.

TABLE III.—RAINFALL FOR SEVENTEEN YEARS.

Year.	Total Rainfall.	Number of Months during which no Rain fell.	Month during which the most Rain fell and amount.
	Inches.		Inches.
1875	4·75	4	June, 2·24
1876	4·33	2	August, 1·12
1877	4·23	4	Sept., 1·37
1878	15·50	3	March, 9·80
1879	10·04	3	Nov., 3·52
1880	6·05	5	Feb., 3·49
1881	10·71	3	May, 3·26
1882	10·48	3	April, 3·14
1883	5·90	2	May, 2·00
1884	7·44	none	May, 2·21
1885	13·67	1	Dec., 5·05
1886	10·08	2	July, 2·71
1887	10·11	2	March, 3·56
1888	3·26	4	Feb., 1·47
1889	16·15	3	May, 4·05
1890	12·00	1	May, 2·39
1891	9·25	3	Jan., 2·70
1892	8·98	3	Nov., 1·95
Mean (eighteen years)	9·05	2½	..

TABLE IV.—EXPENDITURE ON PLANT, MACHINERY, BUILDINGS, &c.

	£
Mine-plant and machinery, including rock-drilling plant	109,635
Smelting-plant at the mine	120,136
Concentration-plant at Broken Hill	39,648
Lands, buildings, wharfs, coke-bins, &c.	97,571
Lixiviation-plant	15,104
Amalgamation-plant (not yet completed)	36,880
Tanks	7,345
Railway-sidings and connections at the mine and wharf	11,819
Refinery-plant and smelting-plant at Port Pirie . . .	24,389
Electric-light plant	9,077
Total	<u>471,604</u>

[DISCUSSION.

Discussion.

Mr. Hayter. MR. HARRISON HAYTER, President, said it was some time since the Institution had brought before it the subject of mining operations of the nature of a Paper. The members, therefore, would be glad to have the subject reintroduced, and that by a description of one of the largest and most successful mines in the world. He did not think that it could have been dealt with in a more complete form, and he hoped that the Paper would elicit a good discussion. He was sure it would be the pleasure of the members to return their thanks to the Authors for their descriptive, and thoroughly practical Paper. Unfortunately they both were now in New South Wales, and it would be necessary to discuss the Paper without them.

Dr. Ball. DR. E. J. BALL said he had not expected to be called upon to open a discussion covering so wide a field both in mining and metallurgy. On listening to the Paper it appeared strange to him, as it no doubt appeared strange to others, that so many processes had been introduced for practically the same purpose, namely, the desilverization of the ores mined by the Broken Hill Company—processes which formed an epitome of the metallurgy of silver. No doubt those ores were very varied in their character. At the same time it would seem that the large number of processes which had been suggested must be due in some instances to individual idiosyncrasies, and must in many cases have represented a considerable waste of money. In the case, for instance, of the lixiviation plant, he assumed that the original idea for the erection of that plant lay in a desire to treat ores of low grade; but when it came to carrying out in practice the laboratory experiments it was found that the process was not suitable, and in that way it became necessary to adopt an additional process, which in order to be economically successful would necessitate the ore being of a higher grade. The amalgamating plant would no doubt be a success; but it might be doubted whether the estimated costs, both in the case of the lixiviation process and in that of the amalgamating mill, would be as low as those mentioned in the Paper. As to the smelting processes, it had become a serious problem to determine a suitable method of treating the complex ores, which were so intimate a mixture of galena, blende, and silver ores that the original pro-

cesses which were in common use were incapable of effecting Dr. Ball. an adequate separation. He understood that Professor Schnabel suggested that a process should be adopted which practically consisted in a roasting followed by leaching—much such a process as the one formerly in use at Freiberg, and still, he believed, in successful use at Clausthal. Whether, however, such a process would be successful at the Broken Hill where the local conditions were so much more unfavourable, where water and labour were dear, and fuel was also costly, was open to considerable doubt. Possibly, they might have to look, for the successful treatment of those ores, to some such process as dry separation. He understood that one such process had shown that it was possible to effect a very considerable separation, but there still remained a large proportion of a waste product, high in zinc, in silver, and in lead, the silver appearing; to follow not merely the lead, but also to pass away with the zinc. Possibly some form of preliminary roasting might enable that waste product to be still further treated. However that might be, it was self-evident that whoever was entrusted with the control of such a complex and important series of processes as those which were in use at the Broken Hill, must not be simply a specialist, but must have a wide knowledge of the whole of the art of metallurgy; he should be able not simply to employ a process but to adapt it to the purpose for which it was required under modified local conditions; he should be able to invent as well; and, more than that, he should be able to prevent his inventive faculties from being allowed too wide a scope at a time when large profits were being made, and when the necessity for keeping down expenses to the lowest possible minimum was not so apparent.

Mr. W. W. WILLIAMS said that his experience concurred with the Mr. Williams. statement of Dr. Ball that silver frequently followed both lead and zinc. On a recent occasion he had endeavoured to learn¹ whether the metallurgists could not devise some way of saving the silver which was in the zinc instead of letting a good deal of it go up the flue of the chimney. He had seen concentration carried out with great success with ores poor in silver. When he was buying some silver-lead ores from the Oezumatlan mines belonging to the British Consul-General in Mexico City there was exactly the same proportion of zinc as that stated in the Paper, 23 per cent. He stated at the time that the ores were unsuitable, and after concentration the product was only 2½ per cent. of zinc. That was the case with

¹ Minutes of Proceedings Inst. C.E., vol. cxii. p. 185.

Mr. Williams. galena ores which were poor in silver, but when concentration was tried with ores that were rich in silver, the silver kept with the zinc in the same proportion as it kept with the lead. He hoped that some metallurgist would hit upon the means of treating the zinciferous residue, thus saving the silver and possibly also the zinc.

Prof. Jamieson. Professor ANDREW JAMIESON said that the Paper gave a very accurate account of the rise and progress of the Broken Hill Mines, but the description was so much of an historical nature that it left very little room for discussion. He had, however, handed the Paper to his colleague Professor Humbolt Sexton, who had favoured him with some notes on the subject. That metallurgist thought that the occurrence of "horses" pointed to the deposit being a true vein, and not a mineralized belt as suggested. Professor Sexton also observed that "methods of treatment described were no doubt satisfactory for the class of ores that had been found—the oxidized ores. But the most interesting and important metallurgical problem (the treatment of the complex sulphides) had barely been touched upon. This was a problem of very great metallurgical interest. Ores containing 32 per cent. of galena and 35 per cent. of blende, could not be treated by the usual processes. Dr. Schnabel, in his report last year, dealt exhaustively with the matter as it then stood, but was not able to strongly recommend any process, except in so far as saying that some process must be used in which the zinc was removed before smelting. The recently suggested dry concentration process might do something towards working these refractory ores, but most certainly it had not yet done so with sufficient profit." As an electrical engineer he (Professor Jamieson) was more interested in the description of the electric lighting plant from which he gathered that twenty arc-lamps and seven hundred glow-lamps had cost £9,077—a price that must have afforded a very good profit to the man who supplied them. Although some captious critics might say, on reading the description of this installation, that the whole arrangement of the plant was antique; still when they considered the great distance of the mine from the makers of boilers, engines and dynamos, they would allow that the leading feature had evidently been that of strength and simplicity. It would be seen from the description, that they had five Lancashire boilers and three non-condensing horizontal engines. Those engines, moreover, were coupled to three sets of countershafts, which in turn drove the dynamos by means of belts. But the most extraordinary feature was that not only were the dynamos duplicated but each primary

dynamo as well as the duplicated dynamos had a spare armature. Prof. Jamieson. The speaker then gave an account of the starting of the Broken Hill mines in 1885 by his brother William Jamieson, who had been the Government Mining Surveyor of the district. He explained how the natural richness of the ore enabled the Proprietary Company from the very start to provide all the necessary material and plant without once making a call upon the shareholders. Indeed, each of the original fourteen shares ultimately became worth upwards of £1,000,000.

Professor ROBERTS-AUSTEN said it was not very easy to discuss the Paper from a metallurgical point of view, for, notwithstanding the imposing dimensions that were given to the smelting furnace shown on the diagram, neither the metallurgy nor the assaying had attained anything like their full development. No doubt the directors had very great difficulties before them in treating the material, one element of which, the sulphide ore, contained no less than 23 per cent. of zinc associated with 27 per cent. of galena. Those difficulties would no doubt be overcome. The astonishing richness of the deposit was truly remarkable. There was one point of very great interest to him, that connected with the cost of producing silver. Some years ago (1887) he gave evidence before the Gold and Silver Commission, then presided over by Mr. A. J. Balfour. Taking all the silver produce in the world, he endeavoured to estimate the cost of production of the silver extracted by the several known methods, and he came to the conclusion that the mean cost of producing silver is 1s. 8d. per ounce. Silver might in certain cases be extracted for a few pence, but the silver which cost most to extract was that obtained from lead by the ordinary methods of desilverization. He put the cost in that case at 2s. per ounce, and he found in the Paper that the cost of producing and disposing of the silver in the lead for the half year ending 31st May, 1892, had been 2s. 3d. per ounce, or, allowing the profit on the lead to go to the reduction of the cost of silver, the net cost was 1s. 10½d. per ounce, including capital expenditure such as plant and development work. Combining those two figures, the result was a sum very near indeed to the cost of producing silver from lead as he had stated it before the Royal Commission. The cost of the production of silver was a matter of enormous importance to the bimetallists in considering the vexed question of the establishment of a dual standard. It was a result extremely interesting to himself personally, but he dwelt upon it as being one of the most generally interesting points developed in the Paper, because they had before them a deposit of enormous

Prof. Roberts-Austen.

Prof. Roberts-Austen. richness, which had already yielded no less than £8,000,000 sterling, and which was still turning out silver at the rate of 220,000 ounces a week. Yet, with all these advantages, the Broken Hill Company were not able to produce silver at a cost lower than the average elsewhere.

Prof. Foster. Professor LE NEVE FOSTER congratulated the Institution upon having so lucid an account of such an interesting district. It was one to which the attention of miners in the country had been directed ever since the year 1887, when a very fine collection of "gossans" was shown at the Colonial Exhibition. He might call attention to the analyses of ore in the Appendix in which the iron was reported to be in the ferrous state. Some of the analyses appeared to him to be incorrect. In the first analysis the figures added up to 99·5, and yet the lead was put down in the metallic state. If allowance were made for its being combined with some other element the analysis would come out too high. Again, it was most unlikely that all the iron in the iron-ore should be in a ferrous condition. Taking the second analysis—2. Carbonate of Lead-Ore—the figures added up to 99·4, and again the lead was put down in the metallic state. Allowing for the missing oxygen, which was necessary to produce the carbonate of lead it would be found that the total would be more than 100. Some correction, therefore, was required for these figures. The Author had appeared to think that there was a connection between rich silver mines and arid and barren countries. It appeared to him that they were arguing on insufficient premises. At all events, in Europe one could hardly say that that was the case. For instance, the forests of Kongsberg and of the Hartz are a proof that moisture is not lacking. Although the soil was not remarkable for its fertility, it could not be said that the silver mines at Freiberg, Przibram and Schemnitz were in arid and barren countries. It was easy to understand that in the early days of a mine it was impossible to define precisely the geological nature of the deposit; but some elucidation might have been given by marking upon the section the dip of the enclosing or surrounding rocks. It might be interesting to note that in Devonshire we have a belt of garnet rock containing copper which has been regularly mined. With reference to the square sets, Hague stated in 1870 that that system of timbering was introduced on the Comstock lode by Didesheimer; the name seemed to indicate that he was a German, or of German extraction. Considering the security of the system with regard to life and limb, one hardly liked to breathe a word against it; but according to the figures in the Paper, and to the figures with reference to the Comstock lode,

the cost was very great indeed, and unless the space was filled up with waste, there was danger of fire, especially with the Oregon pine. One point in the Paper had been somewhat slurred over, viz., the injury to health. It was not said what the injury was, the word "lead-poisoning" was not even mentioned. Probably no mines in the world had ever given rise to so much lead-poisoning as those at Broken Hill. The newspaper accounts might possibly have been exaggerated, but it was stated in 1891 that eighty men were constantly off work from plumbism and that many had died from this disease. No doubt the poisoning was caused partly by the inhalation of dust and partly by the men eating their food with their hands covered with lead-ore, or, as had been suggested, by smoking tobacco which had been rolled in the leady palm of the hand before it was put into the pipe. He was glad to find that the use of the spray had been introduced to keep the dust down. With regard to ventilation, it had been said that carbonic anhydride was present, but it was not stated definitely whether it was given off naturally from the lode itself, though probably that was the meaning of the Authors. Although he had offered these criticisms, he wished it to be understood that he was fully aware that it was far easier to pick a few holes in a Paper than to write one; he had derived a great deal of information from it, and was delighted to think that it would be published.

Mr. S. HERBERT COX said that the theory had been propounded that the Broken Hill lode had been filled by a hot spring. He might mention that some years ago Mr. Jack, the Government geologist in Queensland, had ascribed this origin to the Mount Morgan deposit. It appeared to him (Mr. Cox) that there was a tendency to follow in the lines of any new suggestion of that sort without considering where it led. In the present case he could not see any reason for supposing that hot-spring action could have anything to do with it. He imagined that all engineers and geologists would admit that hot water was very likely the original source of the mineral; but a spring seemed to imply that the lode was filled at the surface, that a spring issued at the surface, and that the deposit was one that was formed at the surface. That he did not believe any mining engineer would admit in the case of the Broken Hill mine. The Paper was one of great interest to all mining engineers, as giving a full description of the way in which the mine had been opened out and worked, and also as pointing out the difficulties that had been encountered. But it appeared to him that the Broken Hill district, and the Broken Hill Proprietary Mine in particular, had had comparatively few difficulties

Mr. Cox. to contend with, and that although such a small amount of money was called up at first—£18,000 being the total subscribed to equip the mine—there had been a very large sum expended on the works of the mine, namely, £471,000. One was led to the conclusion that there had been some mistakes made at the Broken Hill, as at other places, and that, had it not been for the exceptional richness and character of the mine, possibly even with the very skilled management that had been engaged, and the large salaries that were paid, the mistakes which were made might have led to the collapse of the mine. The Paper stated that the concentration works had been tried and not been found successful. Fortunately for the Proprietary Mine, it appeared that the British Company had spent most of the money on those experiments. The leaching works had been more or less successful at the outset, but when the whole plant was erected it had not been so successful as it was supposed to be at first. Other expensive experiments had been made, the cost of which no mine but the Broken Hill could possibly have withstood. He did not call attention to those things in a carping spirit, but simply in order to point out that very often it was a good mine which made a good manager, and that a mine of that sort would stand a great many mistakes that other mines would not. From the start of the mine everything that had been erected had, he believed, been of the most substantial character. The electric lighting plant he did not think was an exception. In regard to the cost of the machinery, for example, he understood that in Block 11 the winding plant had cost something like £6,000, and the winding was only something over 200 feet at that place. A subject of that sort led them to a consideration of what difficulties had to be contended with in mines that had not the same character as the Broken Hill, and he thought they might all draw very instructive lessons on that subject from the Paper.

Mr. Brough. Mr. B. H. BROUGH said that the subject of the geological occurrence of the Broken Hill deposit was one of considerable importance in view of the future productiveness of the mine. The Authors had not attempted to form any definite conclusion on the subject, and they seemed to be very doubtful whether the deposit was a fissure vein or not. The recent investigations by the Government geologists, Mr. E. F. Pittman, and Mr. J. B. Jacquet,¹ two distinguished Associates of the Royal School of Mines, appeared to prove that the Broken Hill deposit was what the late

¹ *Sydney Morning Herald*, 11 October, 1892.

Mr. John Arthur Phillips¹ called a "segregated" vein, which Mr. Brough. differed from an ordinary fissure vein in the fact that, instead of occupying a fissure cutting across the bedding planes of the surrounding rock, it was deposited in a fissure formed between and parallel to the strata. The saddle reefs of Victoria, to which the Broken Hill deposit had been compared, differed from ordinary segregated veins in occupying fissures which, owing to the contortions of the strata, had assumed the shape of an inverted trough or saddle, instead of lying in one plane. Should that analogy to the Bendigo deposits hold, eventually the eastern and western legs of the Broken Hill deposit might be expected to thin out. But there was a possibility that other similarly shaped deposits would be met vertically below the one that was now being worked.

Mr. B. KITTO said that as to the question whether the deposit Mr. Kitto. that had been worked was one of a series of saddle-backs, perhaps a statement could be made whether the ore met with in Kelly's shaft, which must have gone down vertically through the "horse" and cut another deposit of ore, was similar to the oxidized ores met with in the upper portion of the part that had been worked, or whether the sulphide ores had been encountered there. It appeared that mining operations had not extended very far into that second deposit, but one would like to know if any idea had been formed whether it really split up into two veins, as the other deposits had done. With regard to the sulphide ores, there could be no doubt that they could be treated; the only question was as to the cost of treatment, and whether the ores giving the analytical results shown in the Paper would bear the cost necessary to separate ores containing that amount of lead and zinc as sulphides.

Mr. D. A. LOUIS said he agreed with some previous speakers in Mr. Louis. considering the geological features both highly important and interesting. He was also of opinion that the value of the excellent sections and plans furnished in the Paper would have been very much enhanced had they included some indication of the dip and strike of the country. But, in spite of this deficiency, he gathered that the strike of the country was generally in a north-western direction and the dip also north-westerly; whereas the general direction of the lode was north-east and it dipped westerly. There therefore appeared to be a lack of conformity in these respects, which would preclude this deposit from being regarded as a saddle reef similar to those occurring in

¹ "A Treatise on Ore-Deposits." London, 1884, p. 89.

Mr. Louis. the Bendigo district, where, as it is well known, the ore deposits conformed, with great regularity, to the strike and multitudinous foldings of the beds of slate and sandstone between which they mostly occurred. Moreover, judging from the information now supplied, there were other points of difference. Mr. Kitto had asked whether the condition of sulphide ore being found at a lower depth than the carbonate ore might be an indication of the tapping of a new saddle; that, however, was not necessarily the case, for in the Leadville silver-lead deposits, where there was no question of saddle reefs, the same characters obtained; that was, where there had been exposure to the action of waters draining from the surface, carbonates and many of the other products mentioned in the Paper were encountered, whilst in lower portions of the same deposit, if such waters had not had access, undecomposed sulphides were generally met with; in fact, the carbonate and sulphide ores gradually merged into one another. That would therefore not appear to be any indication of saddle reefs, since one might find carbonate or sulphide ore in any lode according as to whether active water had got down or not. The net-work of dykes, the lenticular patches of quartz, the crumbled character of the country among other points alluded to in the Paper, would support the view that the deposit owed its origin to the replacement of a fissured and shattered country; and had partially undergone secondary changes. He had noticed in some mines in America where square set timbering was employed, that square ended timbers were used for the longitudinal members; a practice which obviated the trouble of notching these timbers and also gave a stronger appearance to the sets than that exhibited by those now illustrated. It was customary in the Anaconda mine to mine into the country, at intervals, on upper floors and use the rock so obtained for filling in. He asked if it were not possible that dry rot might not, to some extent, be an active agent in expediting the collapse of timbers in the Broken Hill mines? With regard to the dressing operations, the same system had been successfully adopted in at least two localities—at the Lake Superior copper mines and at Anaconda—where ores of comparatively simple composition had to be dealt with, and where practically it was merely necessary to separate one valuable mineral of high specific gravity from worthless material of low specific gravity. The Broken Hill ore, on the other hand, was remarkably complex and demanded the separation of various valuable materials, differing, but comparatively slightly, in specific gravity, as well as the elimination of the lighter worthless matter;

for this purpose the system described in the Paper was quite unsuitable, and it seemed surprising that some other system had not been adopted, such as a roller-crushing scheme combined with either the English system in which screen sizing was practically dispensed with, the concentration being effected in roughing and finishing jigs, or the German system, with elaborate system of sizing and jigging arrangements.

Mr. JENKINS said that they could not but feel sympathy with those who had carried on smelting operations at a place like Broken Hill, where coke cost 44s. per ton, and where it was so difficult to obtain coke of good quality. They were very fortunate, however, in having fluxes near them and in having ores to treat rich in silver. It was to be hoped that they would find some really satisfactory way of treating the complex sulphide by means of the blast furnace, a method that would be possible if the zinc were separated first; for, as several speakers had remarked, it was the presence of the zinc in the ore that gave so much trouble. If only the zinc or the lead were absent from the complex sulphide, the problem would be quite easy. The co-existence of those two metals with the silica gave rise to conflicting requirements. In the refinery, the zinc method of separation that was in use would be more suitable than any other, if only on account of the degree of richness in silver of the lead. It might not be generally known that the zinc could be to a great extent or even entirely replaced by aluminium, which was rapidly becoming cheaper, and which formed a number of alloys with the precious metals more or less insoluble with lead. There was an alloy formed with gold that was quite insoluble in lead, separating readily from it; and to a less extent that was true of the alloys of aluminium and silver.

Mr. T. CLARKSON wished to say a few words with regard to those refractory ores, the sulphides. It had been already mentioned that the difficulty was the presence of zinc, but that was not everything. That was no doubt the main difficulty, but if the zinc occurred with the lead in large crystals, the separation mechanically would be no difficulty at all. If a piece of the sulphide ore was closely examined, taking a clean new fracture, it appeared like a single mineral, but when pulverized and closely investigated under the microscope it was found to be made up of very minute crystals of galena and blende. With a little practice one could easily discriminate between the two. Indeed, even with material passed through the 200-mesh, one could see clearly which was blende and which was galena. Of course a great

Mr. Clarkson. many of the particles were found to be partly one and partly the other. That was one of the chief difficulties, that it was absolutely necessary to crush the ore very fine before any mechanical separation could be effected. That caused a large quantity of practically untreatable slime to be produced. Another difficulty was the mode of occurrence of silver in the ore. The silver did not occur entirely with the lead. Dr. Schnabel had stated that sometimes the zinc carried at least 70 per cent. of the silver contents of the ore. He (Mr. Clarkson) had made a number of tests with British Broken Hill sulphides and had managed to determine the ratio between the silver contents of galena and blende, and had even got so far as an equation by which, knowing the assay of lead and zinc, they could with fair accuracy compute the silver assay. The ratio was about 10 to 1. Fortunately the lead carried the bulk, but, in the case of sulphide from the Central Broken Hill Mine, the ratio was 2 or 3 to 1 in the same direction, but it was not so definite. The sulphide from the Proprietary Mine gave about 50 per cent., or about as much silver with the lead as with the zinc, so that it was really impossible to effect in that case a concentration of the silver. The only thing that could be done by mechanical concentration was to eliminate the gangue, of which there was usually less than 15 per cent. It would greatly facilitate the solution of the problem if there were a good cheap method of treating argentiferous blende. At the present time there did not appear to be one. The zinc smelters did not care to pay for silver; they lost so much of it. Seeing that so much of the silver occurred with the blende it was absolutely necessary to find some process that would deal with it before they could expect much in the way of getting out of the difficulty. One very interesting feature arising from the tests might be mentioned. It was necessary to assay many of the samples. A good man would probably get through six samples for lead and zinc in a day, but they wanted to make several hundreds of assays, and to get a rapid determination of the lead and zinc contents. They found they could do that with accuracy by making a little brass cylinder a few inches long and about $1\frac{1}{2}$ inches in diameter, by weighing it and putting in pulverized mineral, and shaking it down and weighing it time after time, introducing a fresh quantity until they got practically a constant weight. In doing that they of course required first to standardize the arrangement by actual assays. After that had been done they could determine in two minutes, to within $\frac{1}{2}$ per cent., the lead and zinc. It was not found to hold good in sulphides from

different parts of the lode, each one having first to be standardized. Mr. Clarkson. One point was worthy of notice, that the size of the particles was not an important matter. If they took coarse particles, passing only through a 30-mesh and containing 5 or 6 per cent. of zinc, and sulphides passing through 100- or 120-mesh of the same composition, the weight of the same bulk in the cylinder was practically identical. This was rather surprising, but probably the explanation was that although in the coarser material there were larger interstitial spaces there were of course fewer of them. The Authors had mentioned a difficulty in the sampling of the ore. A sampler which he had used, and which gave very good results, might, he thought, be used on a larger scale. There was a hopper mounted on a vertical spindle running on a foot-step. There was a conical valve at the bottom, so that as the material was sent in, it was delivered in an annular stream. Inserted into the stream there was on each side a narrow spout or shoot cutting through the ring of stuff, and taking out a certain percentage which was deposited in boxes. The bulk of the stuff went down a central pipe and ran away into bags. The hopper was rotating, and the narrow little shoots could take away any percentage required. The appliance could be set to 5 or 10 per cent., and seemed to give a very uniform result. What it really did was to take a series of skeleton corkscrews right through the whole contents of the hopper; he had not found any discrepancy at all in sampling in that way. Another difficulty in speaking of sulphides was their friable character; the galena was, of course, the most friable of the minerals, next came the blende, then the quartz, and lastly the garnets. The sulphides contained a great many garnets. He noticed one day a very peculiar circumstance in crushing some of the stuff. After passing through a breaker and a pair of coarsely-set rolls, all the material that would pass a 60-mesh was sifted out, and was found to be mostly galena. As they proceeded they got mostly blende, and finally the material remaining on the sieve was almost clean garnets. He did not think that would give any solution of the main difficulty. It was not of course accurate; there was no definite line of demarcation, but it might be useful in combination with other processes. He was inclined to think that the real solution of the sulphide problem would be the combination of several processes, not one in particular.

Mr. JOSEPH GARLAND had, a few months ago, an opportunity of Mr. Garland. visiting the mine, and owing to the courtesy of the manager and Mr. Howell, had the privilege of going over the works. He had

Mr. Garland. inspected the smelting, amalgamation and leaching works, and also the electric-lighting installation, and he had gone underground to see the mining operations. What had struck him most of all underground were the enormous masses of mixed sulphides lying unutilized. At an adjoining mine, large quantities of the broken ore were stowed away behind the timbers, as "deads" might be seen in a Cornish mine. He expressed to the agent his surprise at the ore being thrown away, and he replied that the time would come when the ores would be turned to account; but at present they could not utilize them. He wished to ask what the Authors meant when they stated that whereas they used to sink shafts without regard to the hanging- or foot-wall side of the lode, they now made it a practice to sink the shaft on the foot-wall side. There might, of course, be some special reason for sinking on that side rather than on the hanging-wall side as was the usual practice; but assuming that the shafts were vertical, it was not obvious, without some explanation, why they should be sunk on the foot-wall side, seeing that the deeper they went the further they would be from the lode, and the longer time it would take to reach it.

Mr. Eoyd. Mr. R. N. BOYD wished to say a few words on the method of timbering the mine, which appeared only possible methods when timbering such a large mass of apparently movable ore. The Authors had stated that they found it advisable to work from the hanging-wall down towards the foot-wall. They were quite right, because if they worked from the foot-wall with such an immense amount of ore, they would have falls (and so they said they had) which would prevent the work progressing very far. He had seen that kind of timbering on a smaller scale in Germany. It was, in his opinion, the only kind of timbering available for such a mass of ore. He did not take the mine in question to be a lode; it was an irregular mass of ore, such as they found in America and other places, which sometimes bulged out, and was sometimes very thin, and sometimes very difficult to work. No doubt that timbering was expensive, but it was the only effectual way of working. It was a question whether it was worth while to spend money on the timbering to get the ore out, or leave it where it was. With regard to the sulphide ores, which the Authors stated were found about the water-level, that was usually the case in nearly all mines. They obtained oxides of different sorts, whatever the metal might be above water-level, and the present case was no exception to the rule. There was one peculiarity worth mentioning, viz., that the kaolin contained more silver than any other

species of ore raised. That was, no doubt, owing to the decomposition of the country, which apparently carried more silver than the ore itself—so it appeared from the analysis. It appeared to him to be rather a strange fact, which he could not explain.

Mr. J. H. FAWCETT stated that he had been connected with the Broken Hill mine from a very early stage of its history, but he would refrain from touching on the tempting subject of its discovery and early working. The Paper was a very able account of the mine, its mining and its ore treatment, written from the inside by men who were thoroughly acquainted with their subject. The metallurgy of Broken Hill, owing to the variety of the ores and the various methods of treatment now adopted, would afford ample scope for one Paper, which might then contain sufficient details to afford room for criticism and discussion. The mining of such large bodies of ore was a subject of great interest to mining engineers, and the Authors had dealt with this part of their subject in some detail. The square set system of timbering which had been adopted at the mine was admirable. It was expensive, especially where timber had to be brought from great distances. It must be evident also that no system of timbering, however perfect, could be relied upon permanently to hold the ground open unless closely followed up by solid filling. That there had been so few serious accidents entailing loss of life in the mine, spoke well for the care with which the work had been laid out and supervised. There had, however, been subsidences and “creeps” sufficient to show the danger which existed in the absence of solid filling, especially amongst the friable carbonate of lead ores of some of the upper levels. In consequence of this and for other reasons, a suggestion had been made some eighteen months since by Mr. W. R. Wilson, then chairman of directors, that the whole of the upper part of the lode should be removed by open cast working. This suggestion met with the approval of Mr. Howell, and after some controversy had been partially adopted, and so far with the most complete success. Although, in order to give the necessary batter a great deal of rock had to be broken down, the cost per ton was small, and the discovery of detached bodies of ore, which would never have been found in the ordinary course of mining, had made the work exceedingly profitable. Quantities of timber were also being recovered from the upper slopes in good enough condition to be used again. It was proposed ultimately to extend the open cast working down to about the 212-foot level at Rasp’s shaft. Professor Jamieson had quoted Professor Sexton’s opinion on the occurrence of “horses” as proving the Broken Hill ore body

Mr. Fawcett. to be a true lode. The fact was that, although these masses of country when first met with, dividing the lode into two portions, the eastern and the western, were supposed to be, and were still locally known as "horses," they had not yet been proved to be so. The latest theory was that the Broken Hill lode was similar to the saddle deposits at Bendigo, and that the "horse" was the cap of the anticline, and so would be the true foot-wall of both the eastern and western legs. In this connection, it might be mentioned that, since the Paper was written, carbonate ore of good quality had been cut at a depth of 210 feet in a shaft being sunk east of McCulloch's shaft. This was 80 feet east of any previously known body of ore, and, according to latest advices, promised to be a valuable addition to the easily treated ores of the mine. The Authors had not referred at any great length to the question of the treatment of the sulphide ores, the reason no doubt being that at present no definite system of treatment had been decided upon, while experiments were going on in all directions. Mr. Howell was himself experimenting, while Mr. Schlapp, the chief metallurgist of the mine, had recently devised and erected a small plant which, he believed, promised to deal effectively with the sulphide ores, but he had heard no particulars and was not likely to do so while experiments were in progress. It was not of course actually a question of the possibility or impossibility of treating the ore, but of treating it economically and profitably. The ores were somewhat complex, but consisted essentially of galena, blende, and gangue, with the silver through all. Had the silver been in the galena only, concentration would have afforded a ready solution of the difficulty, and would have provided a concentrate readily treatable by present appliances at the mine. As it was, all that the best concentration could do, was by separating the galena from the blende to give two products, each carrying silver and each susceptible of easier treatment for the recovery of the silver than the mixture. In this direction good results had been obtained by dry concentration. Some experiments had been made in London, where the company had had about 10 tons treated by the Clarkson-Stanfield concentrator which had made a very good separation of galena from blende and of gangue from both.

The Authors being absent, he would venture to reply to some of the remarks made during the discussion. Some astonishment had been expressed by Dr. E. J. Ball at the "large number of processes" which had been introduced for desilverizing the ores of the Broken Hill mine. Leaving out concentration, which was

only necessary with some of the ores preparatory to their further Mr. Fawcett. treatment, there were but three processes in use at the mine—smelting, undoubtedly the only process for the lead ores, amalgamation, and lixiviation. For the dry ores, viz., the highly siliceous ores and the kaolin carrying silver chloride, chlorobromide, iodide, and native silver, smelting was of course not suitable, although large quantities had been smelted with the lead ores and were still. While that was possible, owing to plenty of lead ore being available, the cost per ton of smelting was thereby greatly increased owing to the additional quantities of basic fluxes necessary. The object in erecting the lixiviating plant was to treat these ores and the tailings from the concentrators. Since the Paper was written a revolving “Howell” chloridizing furnace had been experimentally added to the plant, and the results had been so satisfactory that ten additional furnaces had been ordered. The actual cost for crushing, roasting, and leaching had been, as was estimated by the Authors, about 20s. per ton. Mr. Koehler, the acting metallurgist, had reported “that the loss by volatilization was small, and that an average extraction of from 82 to 85 per cent. seemed assured.” The amalgamating mill was now successfully at work on low grade dry ores, and the cost was not materially above the estimate of the Authors.

A strong point had been made by Professor Roberts-Austen of the fact that the cost of producing silver at this mine for the half-year ending 31st May, 1892, justified his estimate of the average cost of producing the world's supply of silver as given by him before the Royal Commission. Professor Roberts-Austen's opinion on this subject was entitled to great respect, but the fact that the cost per oz. of producing silver from one of the richest mines in the world, paying large dividends, agreed with his estimate of the average cost all over the world, might be held to prove that his estimate was too low. The cost given by the Authors was based on the then average yield of 15 per cent. lead and 37 ozs. silver. During the last six months a greater tonnage of ore had been treated and the total yield of silver had increased, but the average value of the ore treated had been about 11 per cent. lead and 29 ozs. silver. With regard to the errors pointed out by Professor Le Neve Foster in the analyses of the various ores, it was evident that except in the last, Pb should be PbO, as CO₂ is accounted for below, FeO should be Fe₂O₃, and Zn should be ZnO. Other errors had also crept in, but if these corrections were made the analyses did not work out so badly, although in

Mr. Fawcett. some cases they did not leave room for much silver. Lead-poisoning at Broken Hill had no doubt been caused in the various ways enumerated by Professor Foster. Among the friable carbonate ores it has been inhaled, absorbed through the skin, and taken with food and drink. With the present improved ventilation, use of compressed-air drills, and sprays to keep down the dust, cases of lead-poisoning were now of less frequent occurrence. The great outlay of plant and the probability of expensive mistakes having been made had been alluded to by Mr. Cox. Partly owing to the tenure on which the mine was held, development was pushed on rapidly and with great spirit and enterprise on the part of the directors from the first, and it would be strange indeed if no such mistakes had been made. On the whole this bold policy had been justified by results, and it was probable that few undertakings on so large a scale had been so successfully conducted throughout. In reply to Mr. Garland, the recently sunk shafts were on the foot-wall side of the lode, in order to keep the shafts in sound ground and out of the lode, the underlie of which was very slight.

Mr. Jamieson. Mr. M. B. JAMIESON, on behalf of Mr. J. Howell and himself, stated, in reply, that in regard to the very varied character of the processes of ore-reduction mentioned by Dr. E. J. Ball, it might be noted that the various plants were erected as the development of the mine disclosed different classes of ore in sufficient quantities. The works were brought into use in the following order:—Smelting, Concentration, Refining, Leaching, Chloridizing, Roasting and Leaching, and Amalgamating. If the mine had been thoroughly opened out before reduction operations were started, it was quite possible that the processes would have been fewer in number.

The electric-lighting plant had not been, as Professor Jamieson's remarks would imply, a costly one, neither was it antique. Although the steam was obtained from five Lancashire boilers, it must not be inferred that the whole of these boilers were used for the electric-light plant alone, for these boilers were in existence some years before the property was supplied with electric light, and they still afforded steam to other portions of mine plant. There were not three sets of countershafts, but three sections, which, when coupled, formed one countershaft. The great lengths over which the insulated cables had to be carried to supply every building of importance on the property and each plat of every shaft, rendered a considerable outlay imperative for this class of material and fittings. It might be interesting, in

connection with Professor Roberts-Austen's remarks on the large dimensions of the smelting furnaces, to state that at the British mine there were two furnaces at work (and a third under construction) of considerably larger dimensions than those at the Proprietary Mine. These larger furnaces (designed by Mr. Howell) had steel water-jackets from the top of the ordinary cast-iron jackets up to the feed-floor. They were 56 inches by 132 inches, and were popularly termed 100-ton furnaces, while the furnaces at the parent company were similarly designated 80-ton furnaces. These larger furnaces did excellent and economical work.

In reply to Professor Le Neve Foster, the words in the Paper "injury to health, directly attributed to working in the lead stopes," were intended to refer to "lead-poisoning." The Government recently appointed a Commission to consider the question, and a quantity of evidence was taken at Broken Hill. The finding of the Commission was generally to the effect:—

"That leading is an extremely common cause of illness among workmen at the mines when working in the carbonate-of-lead ore stopes, and, but to a lesser degree, on the surface around the smelting-furnaces.

"Probably the townspeople are not subject to leading to any such degree as would leave manifest traces on the death-roll, although the effects of lead-poisoning are more or less observable, especially among children living in the town nearest the smelters.

"Animals, such as cows, dogs, cats and fowls, seemed to suffer from leading within a radius of from one to two miles of the smelters. There are, curiously enough, no sparrows in the district.

"That lead gets into the system in the shape of carbonate-of-lead ore dust, flue dust and smoke (formed in the course of smelting) by way of the stomach, lungs and skin; and that people living in the town may suffer from leading by drinking rain-water obtained from roofs on which fumes from the smelters have settled and been carried by rain into water-tanks."

A majority of the Commission made nineteen recommendations with the view of rendering lead-poisoning less frequent; but Mr. Howell (a member of the Commission) had to dissent from many of the recommendations, chiefly on account of their impracticability. The carbonic anhydride referred to in reference to the ventilation of the mine was derived very largely from the carbonate ores. The timber (Oregon pine) had not, as yet, shown any kinds of decay, and it had been in continual use for over five years.

In reply to Mr. Garland, it might be stated that, before the dimensions and character of the lode had been determined, shafts were sunk at any convenient point. It was soon found that shafts

Mr. Jamieson, sunk within the lode or on the hanging wall were costly to maintain in good order; and in one or two cases resulted in complete collapse. The hanging-wall country, for fully 200 feet in depth, was much decomposed and rotten, whilst the rock on foot-wall side of lode was solid and sound. It had therefore been found, in the long run, wise and economical to sink new shafts, when possible, in the solid foot-wall country. As to the much-discussed question of the treatment of the sulphide ores, it was, at the present time, impossible to say much. For years past, numerous and continued tests had been made, in order, if possible, to find a certain and economical method of saving the valuable metals. That the operation could be done was beyond all question; but the all-important factor was the cost, and the lowest grade of ore which would pay expenses and leave a profit, however small. Scores of men in Australia, some with a metallurgical experience, and some without such knowledge, had devised many schemes for dealing with this class of ore; but it must be admitted that, although many of the schemes would save the greater portion of the metals, the cost of so doing would result more often in a loss than in a profit.

Comprehensive and carefully-conducted experiments had for some time past been carried out at the mine, and from these it was confidently hoped that an economical plan of dealing with the complex sulphides would be established. The high price of labour, fuel, and other requisites prohibited the adoption of any one known method at Broken Hill, but the experiments now being conducted pointed to the fact that more than one process would be necessary to economically save the valuable metals, and that in all probability the first operation would be a mechanical separation (as far as possible) of the zinc and lead sulphides; secondly, a desulphurizing and chloridizing, roasting and leaching of the zinc product; and, lastly, a smelting of the lead product.

In conclusion, the Authors wished to direct attention to the all-important question of the costs of the labour employed. It was a most remarkable fact that since the termination of the strike, the men employed underground had not only earned better wages, but had also given to the owners of the property much better value for the wages paid than during the reign of unionism. What a man earned now was his own; previously it was subject to the capricious and frequently excessive taxation of the union leaders. Broken Hill was for a time unique in that no man, unless he were a member of a recognized union, could earn a living. Now any man, unionist or non-unionist, could, if he proved industrious,

earn wages much above the average in other localities. The Mr. Jamieson. system of stoping ore by contract, or paying by results, was working very satisfactorily, as was proved by the fact that with 943 men underground, 22,064 tons of ore had been raised above the quantity produced during the half-year ending May, 1892, with 1,543 men.

Correspondence.

Mr. A. H. BROMLEY regretted that the Authors had not given Mr. Bromley. particulars of the results obtained with the rolls adopted at two of the mills. For the treatment of ores of the Broken Hill type, roller reduction presented obvious advantages over other methods. A judicious system of gradual reduction by breakers and rolls, coupled with the removal of fines, should overcome the difficulties due to the methods of crushing, whilst those due to the methods of classifying adopted should be obviated by sizing the product over trommels preparatory to jigging, and by sending the slimes only to the hydraulic separators, and thence to buddles or vanners. It seemed, however, extremely doubtful whether a system of mechanical concentration could successfully treat the sulphide ores, on account of the intimate association of the constituents of the ore, and on account of its friability. Reduction, however carefully carried out, would result in the production of 25 per cent. of slime.

Mr. HENRY F. COLLINS thought that the Authors' Paper was Mr. H. F. Collins. valuable chiefly from a mining point of view, the many sections of the ore bodies being specially interesting. The description of the reduction works was somewhat incomplete, the loss in slags, for example, not being touched upon. The furnaces were of an unusual type in several respects, notably in the fact of the tuyeres extending so far into the furnace as to leave only 18 inches space between those on opposite sides. The ores treated did not differ in any marked degree from the mixtures made up at the leading custom works of the Western States of America, and it was difficult to see where the necessity arose for such an innovation, or what advantage was gained by it, experiments having proved that such protrusion of the tuyeres was necessarily followed by a greater or less reduction in the daily furnace capacity. Speaking as a practical smelter he was of opinion that better results would be attained on ores like those at Broken Hill by the adoption of a much larger type of furnace—say 120 inches by 36 inches at the

Mr. H. F. Collins. tuyeres, instead of 54 inches by 30 inches—since the labour cost per ton of ore smelted was greatly reduced by an increase in furnace capacity, while such large furnaces were more convenient for dealing with friable fine ores, and with those carrying a high proportion of zinc. The amount of limestone flux employed seemed at first sight excessive. No figures were given by the Authors as to the average slag composition, but, taking their figures as to the proportions of the different kinds of ore charged into the furnaces in 1891 and 1892, and their average percentage composition, it might be easily calculated that the average slag composition was somewhat as follows :—

	Per cent.
Silica	43·0
Ferrous and manganous oxides	19·6
Zinc oxide	2·3
Lime	20·8
Alumina	9·3
Lead oxide, sulphur, &c.	5·0
	100·0

from which it was evident that little if any reduction was possible in the amount of limestone employed. On the whole it was evident that not much improvement could be hoped for in reducing the smelting costs except by the adoption of a larger type of furnace which would allow of some economy in labour cost.

Mr. J. H. Collins. Mr. J. H. COLLINS observed that it was well known that the best examples of mining and metallurgical practice were usually to be found in connection with poor but extensive ore deposits, while the contrary was often the case where deposits of exceptional richness were concerned. There were obvious reasons why this should be the case, and certainly the account given by the Authors of the works at the Broken Hill mines presented no exception to the latter portion of that general rule. The Paper afforded many illustrations, of which he selected two only for special comment. 1. As regards the "square-set" system of timbering (introduced in 1887, and now so extensively employed that over 100,000 cubic feet were used per month at a gross cost of nearly £11,000), it might, as the Authors stated, be superior to that previously employed; but its enormous cost under existing local conditions, and the great dangers from fire and other causes, inseparable from its adoption under those conditions, should have negatived its use from the first. The Authors had, however, clearly set forth its disadvantages and indicated the system which

should have been employed. 2. The concentration plant described seemed to have been copied without consideration from that in use in several of the great copper mines of the Lake Superior district, where it had proved to be very efficient. But the ore-material to be dealt with differed in almost every respect from that existing at Broken Hill. One of the most effective of the Lake Superior concentrating plants was in operation at the Atlantic mine, where ores yielding only about two-thirds of 1 per cent. of copper, and worth less than 7s. per ton were mined, hoisted from depths averaging about 1,000 feet, crushed, concentrated and smelted at a total cost of a little over 6s. per ton, of which the concentration cost only 1s. 1d., so that a fair profit was left on an out-put of something like 1,000 tons per day. At Broken Hill the absolute value of the ore was not given, but the cost of mining was stated to average £1 8s. 3d. per ton, and the cost of concentration amounted to no less than 10s. 6d. At the Atlantic mine the tailings were valueless, as might be supposed; but at the Broken Hill the process was so little effective that a large quantity of the silver contents of the ore remained in the tailings. They had, therefore, to be subjected to a further costly process of leaching, or of amalgamation. One of the chief factors in the cheap concentration at the Atlantic mine was the abundance of water, no less than 40 tons being used in the treatment of each ton of ore, the ore at the same time being absolutely unaffected by its use. At Broken Hill, on the contrary, water was exceedingly scarce, while the ore was of such a character that a large quantity of water could not be used, even if it were available, without very heavy loss of mineral value. On the whole, considering that this mill had cost close on £40,000, that it had only been able, from shortness of water and from other causes to treat an average of about 100 tons per day, that its working cost was so extremely high, and that the tailings needed a further costly treatment, the remark of the Authors' that "it cannot be considered that this class of machinery will prove successful for the concentration of a similar lead ore," must be regarded as an extremely mild and altogether inadequate condemnation.

Mr. J. H.
Collins.

Professor G. KÖHLER, of Clausthal, stated that it was difficult to express an opinion on the method of working the deposit and of supporting the excavations without having visited the Broken Hill mines, and without having studied the local conditions. He, however, agreed with the Authors that the method hitherto in vogue, with square set timbering and without replacement of deads, did not appear satisfactory, inasmuch as enormous masses

Prof. Köhler.

Prof. Köhler. of wood were consumed, and that wood, having to be brought from Oregon, was very costly. Further, with such timbering the pressure of the strata could not permanently be withstood. If in the workings and in driving the levels sufficient material could not be obtained to be used as support, and if the tailings from the dressing-floor were inapplicable, the requisite deads must be specially obtained either at the surface or underground. He very much doubted whether the square-set method of timbering was, as stated by the Authors, a German invention, for he had never seen nor heard of that method in Germany. In that country all large ore-deposits subject to great pressure were worked exclusively by overhand or by underhand stoping, with replacement of deads. In order to lessen the cost of supports, the haulage levels were driven in the surrounding rock on the foot-wall of the deposit. The method of working was fully described in the text-books on mining.¹ With regard to the dressing of the ore, he agreed with the Authors that the indiscriminate use of stamps was an error, and that at two of the works the stonebreaker and rolls had wisely been introduced. The stamps made too much dust and consequently gave rise to loss. That a successful concentration of the Broken Hill ore was extremely difficult, if not impossible, he had had an opportunity personally of ascertaining. A large quantity of the sulphide ores (galena and zinc-blende) was treated in the Hartz in order to give Professor Schnabel the requisite basis for determining a suitable method of metallurgical treatment. The ores, however, formed so intimate a mixture that it was only by the exercise of a degree of care, that was impossible in ordinary dressing operations, that a more or less satisfactory separation of the galena and zinc-blende could be effected. Similar ores, though in smaller quantities, were raised at the Rammelsberg mine at Goslar and smelted, without preliminary concentration, at the works of the Lower Hartz. It could, therefore, be expected that the method of metallurgical treatment proposed by Professor Schnabel for the sulphuretted ores that occurred in such great quantity at Broken Hill, would prove practicable if the high rate of wages was not an obstacle.

Mr. Sopwith. Mr. T. SOPWITH observed that in Europe metalliferous mining engineers had looked with interest, and he might say with concern, on the great and rapid development of the Broken Hill Proprietary Mines in New South Wales. The Paper was so comprehensive

¹ "Lehrbuch der Bergbaukunde." By G. Koehler. 3rd edition. 1892. pp. 209. Leipzig.

that any remarks bearing upon the production of lead and silver might be considered appropriate; it might be of interest, therefore, to consider the position of that industry now, as against that which it was in, in the earlier times of our own generation. By reference to the reports of the Great Exhibition of 1851, he found that his father, then a Member of this Institution, in charge of the mines of Mr. W. B. Beaumont, stated that the production of these mines in Northumberland and Durham was 8000 tons of lead a year, and they were at that time considered to be, as indeed they were, the most important of their class in the world. At a more recent period, say twenty years ago, when he was himself actively engaged in lead mining, the production of lead in the world was about 300,000 tons, then the average price of lead was £22 per ton; but since that time great changes have taken place; Germany had come to the front as a lead-producing country, railways had developed the mineral resources of Spain, and a large increase in the production of lead was apparent. There were now four or five producers of lead in Europe, with outputs varying from 15,000 tons to 20,000 tons per annum, and two or three in the United States of America. Europe had increased her production from 250,000 tons to 300,000 tons, the United States of America from 47,000 tons to 205,000 tons, making a total production for the world of over 550,000 tons at the present day. This enormous increase had not up to within recent years been accompanied by any great depression in the values of lead and silver, for the increased consumption of lead for purposes of sanitation, and more recently for electrical requirements, had kept up the price, until quite recent times, to £14 to £15 per ton. The new production, however, which came from Australia, and principally from the Broken Hill Proprietary Mines, amounting to over 50,000 tons per year, was more than the markets could stand, and the price of lead had consequently fallen to £9 10s. per ton—a price which, with rare exceptions, was not remunerative to British or German lead mines, nor indeed to Spain, where the producers were favoured by a condition of things—the larger proportion of silver in the lead ores—not general in Great Britain or in Germany. Since the year 1865, European lead producers had faced a difficulty of no small importance, namely, the imposition of an import duty of £9 per ton in the United States of America (then large recipients of British lead), which, at the time the duty was imposed, represented 40 per cent. on the value of pig lead. Though sufficiently onerous, that duty under the conditions of mining trade in Europe was tolerable, but now, under altered conditions of the trade, it

Mr. Sopwith.

Mr. Sopwith. amounted to no less than 100 per cent. on the value of lead produced in Europe, if it were imported into the United States. There was no doubt that the working on a colossal scale of the Broken Hill Proprietary Mines was attended with difficulty and danger, which the Authors of the Paper and the managers of the mine had done much to diminish. Danger was most to be seen in the nature of the mining operations as described by the Authors, difficulty in the refractory nature of the ores which were produced, and which had to be reduced to metallic form. In regard to mining, some of the features might be cited which seemed dangerous, notwithstanding the observations made by the Authors of the Paper, that loss of life had been infrequent. The nature of the deposits could be seen from the drawings accompanying the Paper. As ore was removed, means must be provided *pari passu* of fortifying the space which had become void, and hitherto it appeared that at Broken Hill that had been done by an elaborate system of timbering, a system which did not appear satisfactory in regard to long-continued mining operations. Taking into consideration the perishable nature of the material (timber) used, its liability to take fire, either by accident or by incendiarism, and the great width which had to be occupied, such a system of fortification could not be regarded as likely to be permanent. When large masses of ore had been removed, any slight movement of the ground either lateral or vertical, would, so to say, convert this timber scaffolding into a box of matches. He quite agreed with the Authors in the remarks they made, but which, in his opinion, they had not given sufficient prominence to, that fortification by masonry should replace in a large degree the system of timbering as now practised. Fortification by masonry would be permanent; it would take the form probably of a series of curtains or diaphragms from the foot-wall to the hanging-wall, but it would obviously present certain, though not insuperable, difficulties as ever increasing depths of the exploratory levels were reached. As a metalliferous mining engineer in Europe, and having regard to European powers of competition with a comparatively new enterprise such as that of the Broken Hill Proprietary Mines, he was profoundly impressed by statements authoritatively made by the Authors. In British lead mines all the ore from which contained more or less silver, the intrinsic value of a ton of "vein-stuff" varied from 10s. to 20s. per ton. In Germany the Mechernich Lead Mines, which next after the Broken Hill had the largest output of lead in the world, dealt with material the intrinsic value of which *in situ* did not exceed 4s. 6d. to 6s. per ton. Gold mines, which

to those who had not been associated with their development and Mr. Sopwith. working were supposed to be real mines of wealth, were, as a matter of fact, worked under conditions where, taking one ton with another, the intrinsic value of material removed did not in many cases exceed 3s. per ton. A good Spanish lead mine might represent a value of 16s. to 25s. per ton for ore matter *in situ*, but at Broken Hill, from an average of nearly 1,000,000 tons extracted, the material excavated had represented the value of no less than £4 per ton; so, notwithstanding that miners were paid 10s. per day, and artizans from 10s. to 12s., and that coal cost 45s. per ton, an ample margin was left for many years of prosperity in this great undertaking.

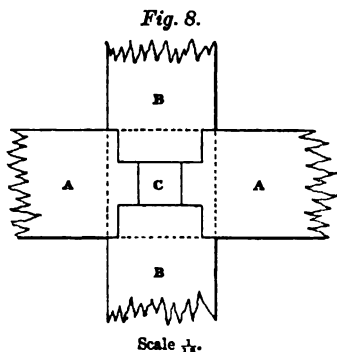
Mr. F. J. WARNER observed that while acknowledging the value Mr. Warner. of the information supplied by the Authors, he noticed that no allusion was made to some rather important items. No particulars, for instance, had been furnished with reference to the losses incurred in smelting, and it was rather surprising to hear that there were no trustworthy means of arriving at these, although it was admitted that customs mills managed to ascertain their exact losses, by having the ore sold to them sampled previous to treatment. Surely what a custom mill could do the great Broken Hill Company could accomplish, and there would seem to be no insuperable difficulty or heavy expense involved in taking an average sample of the ore before it was charged into each furnace. Unless some system of this sort were adopted, it would be impossible to judge of the skill with which the metallurgical operations were conducted, for, as the Authors themselves pointed out, the slags afforded no true test. In spite of the additional expense, it was evident that a proper sampling of the ores would be found as useful at Broken Hill as at other works, and would enable the Company to avoid losses which at present were probably unsuspected. An expenditure of nearly £40,000 for an ore-dressing mill to treat from 150 to 200 tons of ore per twenty-four hours seemed a very heavy item indeed, more especially when it could not be called a success, and that, so far, only some 98,000 tons of ore had been passed through it. One was tempted to ask, how was it that such a large sum came to be expended before the suitability of the plant had been demonstrated on a smaller scale? Surely it would have been better to have spent, say, one-tenth of the amount on a smaller plant at first, and then, if after a practical test it had proved efficient, to have increased it to any desired extent. The cost of dressing—10s. 6d. per ton of crude ore—which was, he presumed, exclusive of interest on capital and depreciation, was very

Mr. Warner. high, but was, no doubt, partly accounted for by the dearness of water. In reference to the cost of smelting, it would have been useful if the Authors had given the cost of coke and the actual loss in handling, as well as the percentage which was required per ton of ore.

Mr. Heathcote. Mr. C. F. HEATHCOTE sent the following particulars¹ relating to the timber-work at the Broken Hill mines :—

The system of mine-timbering known in Australia as the square set, is generally supposed to be of American origin. It is there known as the Nevada system. It was probably first used in Australia about the year 1854, when an alluvial claim, on the Golden Point line at Ballarat, was timbered in this manner with round timber, as is usual in most cases where it is employed.

The timber used at Broken Hill is Oregon pine. New Zealand Remo pine was tried, but was found to break with too short a fracture, so that insufficient warning was given to the timber-men. Tasmanian stringy-bark was also used,



and West Australian Jarra, but their great weight, the consequent heavy railway charges, and extra difficulty in handling underground were against them.

A set of timber may be said to consist of three pieces, the leg, cap, and strut, except in the case of foundation sets, which require sills. *Fig. 8* is a plan of the joint used at Broken Hill, AA are the caps, BB are the struts, and C the tenon 4 inches square on ends of leg. The caps are 5 feet 6 inches long over all, and leave 5 feet in the clear between legs; the struts are 4 feet 8 inches long, leaving 4 feet 2 inches clear between legs; with these dimensions five flooring laths, 10 feet by 2 inches in one direction, or 6 feet in the other, suffice to cover the opening between sets. The legs are 6 feet 10 inches over all, having a 4-inch tenon on each end, so that when the 2-inch floor is laid, there is a clear way of 6 feet in height throughout the level. On all main-levels the legs are 7 feet 2 inches long, or if lining sets are to be put in, 8 feet long, *i.e.*, 7 feet 10 inches, or 8 feet 8 inches over all.

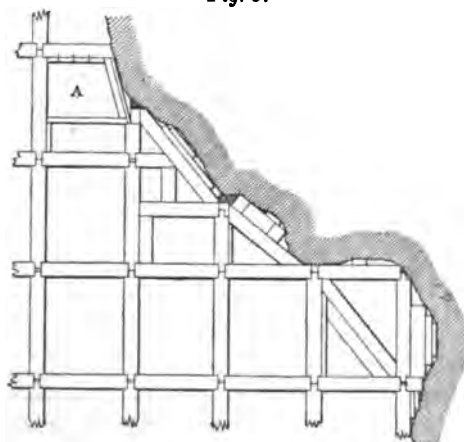
In opening up for a stope, a rise is first put up and timbered with the struts parallel to the line of lode, and, therefore, with the line of caps across the lode ;

¹ This description is abstracted from Paper No. 2725—"Timber-work at the Broken Hill Silver Mines."

from this rise, the stope is worked up in the form of a pyramid, the diagonals of which are parallel to the caps and struts. If head-laths are used, the stopes will carry a pair of men to every three or four sets on each floor; but it is safer to have the men working on alternate floors, on the same side of the stope, north, south, east, or west as the case may be. When laying the foundation-sills for the bottom set, care must be taken, if this foundation is to be removed at some future date, to put in as many double cap or strut sills as possible, and to mark their position so that they may be more readily picked up from below. When ground overhead is worked, or being worked out, the apex set of the pyramid, when within 35 to 50 feet of it, is carried straight up, and the adjoining sets are carried up, one by one, in the same way, and the overhead timbering carefully picked up. This, of course, is often, if the ore is at all friable, a difficult piece of work, as the ore will be crushed into sand, and liable to run at any moment.

When working up the foot-wall of the lode, short legs have to be used, and

Fig. 9.



Scale $\frac{1}{4}$ in.

these are liable to sway, so that plenty of packing must be used to make a continuous bearing. This is also the case with the timbering for the hanging-wall, of which *Fig. 9* is an actual section as put in; this figure shows a weak spot at *A*, which, however, was secured by horizontal angle-stays.

The men, when at timber work, are provided with a level, hand-saw, axe, and sliding-rod with two adjustable short-arms at each end, fixed as required by thumb-screws, in addition to ordinary mining-tools, so that they may measure and cut any special piece of timber as soon as it is required.

In the event of any movement of the timber taking place, or being expected, lining sets *A*, *Fig. 10*, or angle-stays *B* may be put in, which may be strengthened, as in *C*, *D*, *E*, or if necessary *F*, making a 10-inch wall of timber. A hollow or a solid pillar of timber may be used when the vertical pressure becomes excessive. Angle-stays of 10 inches by 4 inches or 10 inches by 10 inches must also be used where required horizontally, to prevent slewing of the sets.

In soft ground back-laths and side-laths may be used, with a false set, if necessary, as in ordinary mining practice. In medium standing ground a "Tom"

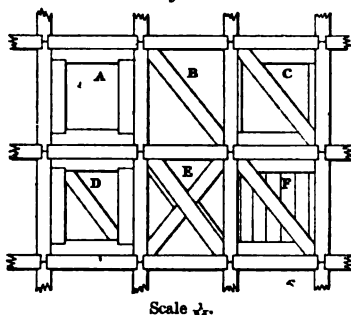
Mr. Heathcote. may be sufficient, though, from the careless way in which some miners put them in, they are often worse than useless.

In the event of a single leg bursting or being insufficient to carry the weight upon it, two or four others may be put round it, the tenons being sawn off. If a cap or strut give way a lining set will suffice.

In March or April, 1890, a very severe creep began in the south stopes of the British Broken Hill Proprietary Company's mines, from the 200-foot level upwards, which could not be arrested, and ended finally in the complete loss of these workings, including the No. 3 shaft. The main drive at the 200-foot level was, however, with great difficulty kept open, so that work could be continued between the crushed ground and the north boundary at the Block 14 S. M. Co.

Owing to the great width of the Broken Hill lode in many places, and the friable porous nature of the oxidized ores, the weight that has to be supported by the timbering is, at times, excessive, and this was added to in the case of the British Company's mine, by the existence of a vough on the hanging-wall

Fig. 10.



extending from a depth of 250 feet up to within 59 feet of the surface, 200 to 250 feet in length, and from 2 inches to 10 feet in width. This vough had been cut in two or three places before the crush took place, but there was nothing to indicate that it was continuous; the extra weight due to this vough may have been considerable, for fracturing weight, or supposing it to have been loose material, the friction, even on this surface, would have amounted to a large total. After the movement commenced, the pressure, of course, became greatly intensified, pillars of 10 inches by 10 inches timber, 20 feet square, were built up in the mine in hopes of arresting it, and in these, pieces may now be measured 10 inches by 4½ inches in section. The Author saw a piece 10 inches by 10 inches pine, pulled out during work, which, where it had been caught between two others, measured only 4 inches, and a 10-inches by 4-inches Jarra lath, treated similarly only 10 inches by 2 inches. The final collapse took place on Sunday, 11th May, 1890. The work of recovering and re-timbering the lost ground was at once commenced, and has since been continued. The mode of procedure adopted is described in detail by the Author.

16 May, 1893.

HARRISON HAYTER, President,
in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Members.

ARTHUR JOHN BAREY.	CHARLES ELWIN.
FRANCIS BOYNTON.	WILLIAM FERGUSON, M.A., B.E.
WILLIAM PALLISER COSTOBADIE.	ARTHUR DANIEL JONES.
EDWIN WILLIAM DE RUSSETT.	HARRY JAMES THOMPSON.
JOHN CLOUGH VAUDREY.	

And that the following Candidates had been admitted as

Students.

RUSTAT BLAKE, B.A.	CHARLES ROMILLY HEWITT.
HARRY GREAVES BRADSHAW.	HENRY THOMAS MATHER.
ARISTIDES STEPHENS CAROUSO.	JOHN RHYS MORE.
LEWIS PERCY CAZALET.	GANAPATHY SWAMY IYR RAMIAH,
JOHN HENRY CHALONER CHUTE.	B.C.E.
HENRY BONIFINT GORDON WARREN.	

The Candidates balloted for and duly elected were : as

A Member.

WESLEY WILLIAM WILSON.

Associate Members.

ARTHUR ALAN ASHWORTH, B.A., Stud.	THOMAS EDWARD WHEATLEY MELLOR.
Inst. C.E.	REGINALD WILLIAM NEWMAN, Stud.
EDWARD HENRY BECKETT.	Inst. C.E.
FREDERIC HUGH PAGE CRESWELL,	GUSTAVE CHARLES REINHOLD, Stud.
A.R.S.M.	Inst. C.E.
RICHARD FREDERICK DODD-CLARKE.	HENRY FINES RICHARDS, Stud. Inst.
EDMUND ALDERSON SANDFORD FAW-	C.E.
CETT, Stud. Inst. C.E.	WILLIAM ARTHUR RICHARDSON.
JAMES FLACH.	JOHN ROSS.
CHARLES FRANCIS HEATHCOTE.	THOMAS FRAME THOMSON, Stud. Inst.
ARTHUR HOARE.	C.E.
CHARLES RYDER JACOB, R.N., Stud.	GUY LAURENCE TILL.
Inst. C.E.	EUGENE HORACE TREBY.
CHARLES MORRIS JENKINS.	CHARLES EDWARD VERNON.
HENRY McMILLAN.	JOSHUA ARTHUR PAGET WADDINGTON.

Mr. HAYTER, President, announced with sorrow that since the last meeting one of the Members of Council, Mr. Edward Alfred Cowper, had passed away. He had been a regular attendant at the Meetings, and had often taken part in the discussions, his remarks being always apt and to the point. Like his father, whom the President knew well, he was a born mechanic, and though he had never constructed any large public works, owing to the particular nature of his calling, he had done much useful work in his generation. His life had been governed by a high moral standard, which he had faithfully acted up to. The Council had at their meeting passed the following resolution:—

“That this Council desires to express great regret at the loss of its colleague, Mr. E. A. Cowper, and to convey sincere sympathy to his Widow and family in their sad bereavement.”

In that resolution he asked the members present to concur, in order that their acquiescence might be incorporated with the resolution, which would thus have additional value in the eyes of his family, his relatives, and his friends.

(*Paper No. 2691.*)

“Wreck-raising in the River Thames.”

By CHARLES JAMES MORE, M. Inst. C.E.

THE raising of sunken vessels is an important duty devolving on Conservancy Boards and other harbour authorities, and is one to which, in the case of the River Thames, considerable attention has been directed for many years past. The casualties in a comparatively narrow waterway, crowded with craft of every size and description, must necessarily be numerous. Soon after the control of the river passed into the hands of the Conservators, they became convinced of the necessity of providing and maintaining, in the most efficient state, the appliances required for speedily raising and removing out of the fairway sunken vessels of large tonnage.

The power to raise or remove wrecks and obstructions was conferred by Parliament on the Conservancy Board in 1857, but was then limited to cases where the owner neglected or refused to undertake the work, after receiving due notice requiring him to do so. In 1870 this power was extended, so as to enable the Conservators to proceed at once with the removal of wrecks without incurring the delay consequent on communications between

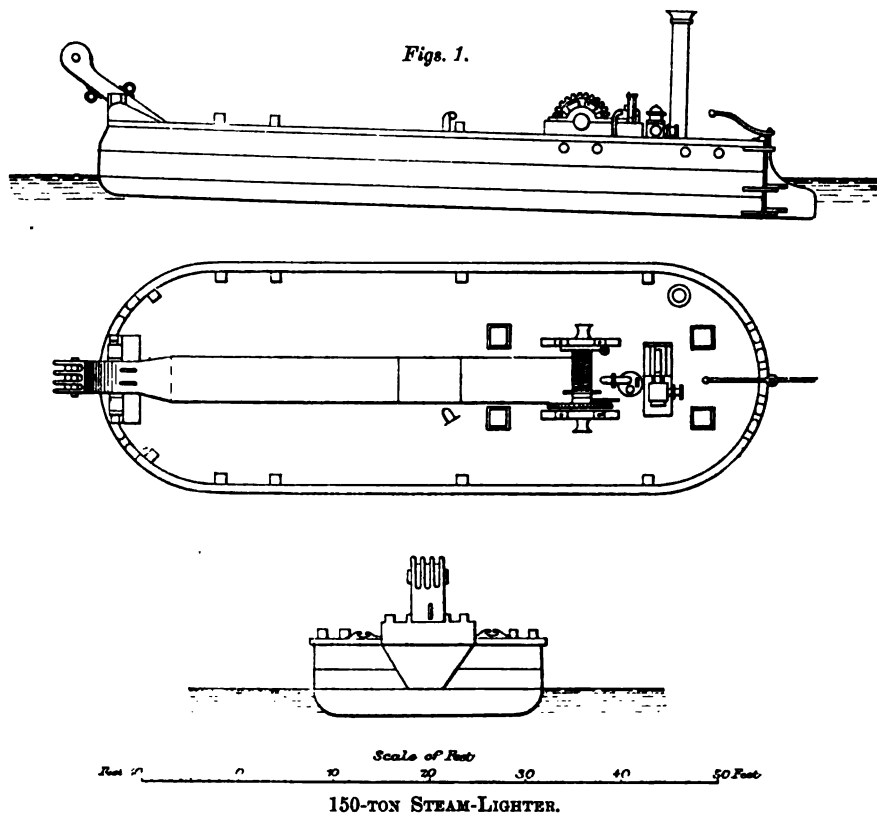
themselves and the owners. The Conservators are also empowered to recover from the owners the whole of the cost and charges incurred in raising sunken vessels, and in the event of non-payment they may sell the vessel and her cargo; and further, should the amount realized by the sale not be sufficient to satisfy their claim, they may sue the owner for the balance.

In organizing the wreck-service, advantage has been taken of the circumstance that the ship's moorings in the Port of London are under the control of the Conservators, and that the examination and repair of these moorings necessitate the continuous employment of a staff of skilled men. All the lighters required for the mooring-service are also adapted for wreck-raising, and the permanent staff of men, well trained to the work, is available at the shortest notice. In addition to the mooring-service lighters, special lighters have been constructed for the sole purpose of wreck-raising, and are kept in constant readiness for use at the Conservancy wharf at Millwall.

The craft available for wreck-raising consist of:—Five lighters, each 70 feet long by 24 feet beam, and having a lifting power of 150 tons; two lighters, each 90 feet long by 24 feet beam, with a lifting power of 300 tons; two lighters, each 108 feet long by 28 feet beam, with a lifting power of 400 tons; the total lifting capacity of these nine lighters is, therefore, 2,150 tons at their ordinary load-line, but by submerging them more deeply, as is frequently done, a much greater lifting power can be obtained. Besides the lighters, there are: A screw steam-tug, 60 feet long by 14 feet beam, with engines of 30 HP. (nominal); a wreck-vessel, stationed at Gravesend, to mark the position of sunken craft in the lower reaches of the river; whilst three wreck-boats are kept at different stations in the upper and less exposed reaches. In addition to these appliances the steam-tug employed in towing barges in attendance on the dredgers is fitted with a powerful centrifugal pump, with a delivery pipe 15 inches in diameter, which can be used at any time when extra pumping power is required. A large quantity of material is kept in stock at the wharf, such as wire-rope, chains, shackles, diving-apparatus, wreck-lanterns, and other gear.

There is nothing special in the construction of the hulls of the 150-ton lighters; they are strongly built of iron, and have stout timber decks, with water-tight hatchways (*Figs. 1*). Three of them are fitted with powerful winches, operated by engines of 12 HP., and have davits 3 feet 6 inches broad, carrying three sheaves, overhanging the bows. Each lighter has also a 10-inch

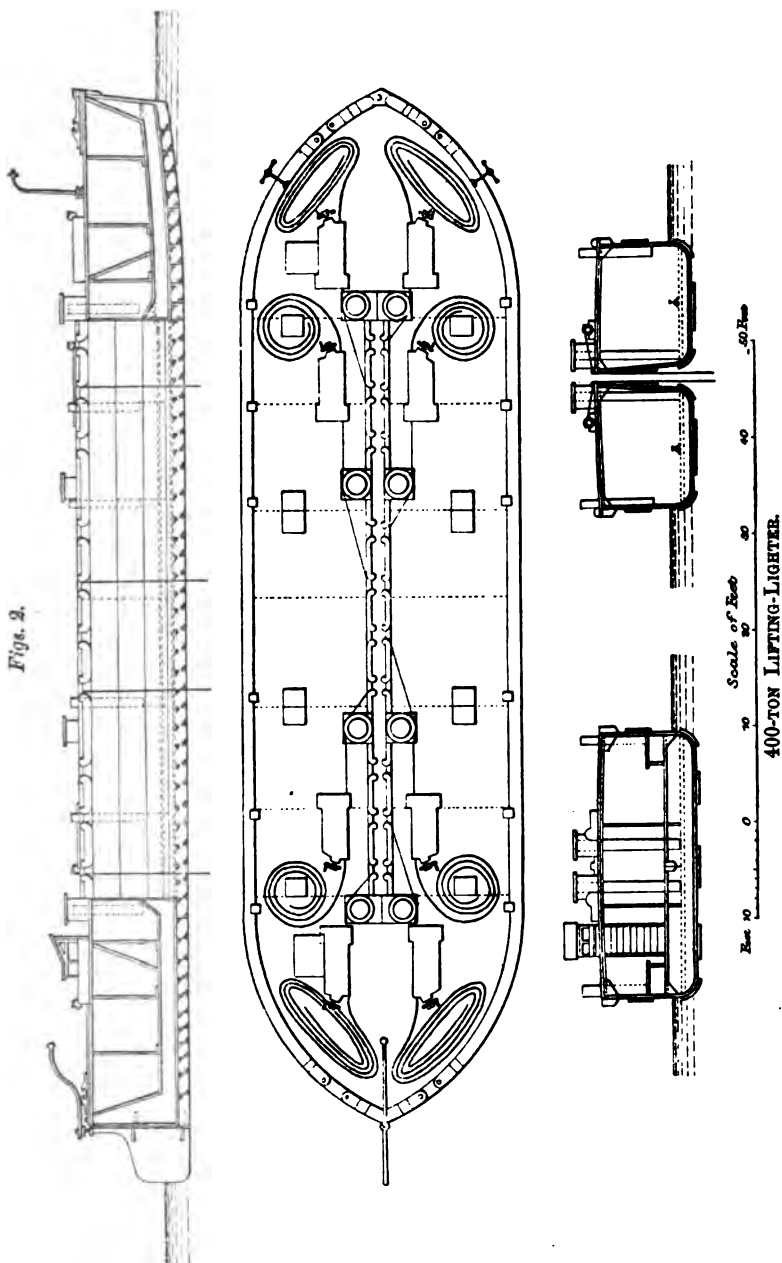
centrifugal pump placed below the deck, worked by the winch-engines. A force-pump fitted on deck is used for charging the centrifugal pump, for scouring away mud or sand, to make a space for passing the wire-ropes under a wreck when necessary, and may be used as a fire-engine. Each lighter has a small smithy, and carries a quantity of stores and material required in wreck-raising. There is also accommodation on board for a foreman and six men.



The 300-ton lighters are built of iron, and are divided into six water-tight compartments. The decks are of timber and the hatchways are made perfectly water-tight, so that the lighters may be completely submerged without danger of sinking.

The 400-ton lighters, *Figs. 2*, are of special design, and require a more detailed description. They are 108 feet in length, 28 feet in width, and 9 feet 6 inches deep at the side. In the centre is an open space or well, 60 feet long by 18 inches wide at

Figs. 2.



the deck-level, and 2 feet at the bottom. The hull is of iron, with stiff cross bulk-heads at each end of the well, making the fore and aft parts perfectly water-tight. The sides of the hull are also connected with the sides of the well by iron plates, so that between the fore and aft holds there are six additional water-tight compartments on each side of the lighter. The deck is of crown Dantzic fir, 3 inches thick, and the gunwales and rubbing-pieces are of oak. The scantlings of the iron are as follows:—The keel-plate stem and stern, $\frac{7}{8}$ inch thick; the frames of iron angle-bars 3 inches by 3 inches by $\frac{3}{8}$ inch, spaced 2 feet apart; floors 12 inches by $\frac{3}{8}$ inch, one to each frame; reverse frames 3 inches by 3 inches by $\frac{3}{8}$ inch from gunwale to gunwale and from side to side alternately; keelsons on each side of well 2 feet by $\frac{3}{8}$ inch; with double angle-bars 3 inches by 3 inches by $\frac{3}{8}$ inch at top and bottom; beams of angle-bars 4 inches by 3 inches by $\frac{3}{8}$ inch, one to each frame; bulkheads of $\frac{3}{8}$ -inch plate, with angle-bars 3 inches by 3 inches by $\frac{3}{8}$ inch, spaced 2 feet 6 inches apart; keel and outside plating of bottom $\frac{7}{8}$ inch thick, inside plates of bottom and sides of well $\frac{3}{8}$ inch thick, top plate of well $\frac{1}{2}$ inch thick; side stringer plates of deck 2 feet 6 inches by $\frac{3}{8}$ inch, with angle-bars 4 inches by 4 inches by $\frac{1}{2}$ inch at gunwale; and stringer plates alongside of well $\frac{5}{8}$ inch thick. On each side of the well ten strong cast-iron fair-leads are securely bolted to the side plates and stringers, for the purpose of keeping the wire-ropes in their proper positions. To give the ropes a direct lead to the holding nippers, four large cast-iron bollards, 30 inches in diameter and 20 inches high, are provided on each side of the well. The nippers which hold the wire-ropes are eight in number, placed four at each end of the well. They are of the pattern known as "Bullivant's Patent Automatic Nippers," and are tested to hold a wire-rope 8 inches in circumference under a strain of 100 tons.

The 400-ton lighters were built by Messrs. J. and G. Rennie, of Greenwich, and cost, with their fittings, about £5,000 each, and the total value of the wreck-raising plant may be estimated at £30,000.

Steel-wire rope is now exclusively employed for lifting purposes. It has great advantages over the heavy chain formerly used, being safer under great strains, and so much lighter and more easily handled that the number of men required on the lighter is considerably reduced. The wire-rope is from 7 inches to 9 inches in circumference, and is kept in lengths of from 2 to 20 fathoms, each piece having a large steel eye at each end to take the lashing when the lengths are joined together. The rope

used in the nippers is in one length, without joints or eyes at the ends, so that there may be no obstruction in slacking it out or letting it run through the jaws of the nippers if necessary.

The permanent staff of the mooring service consists of a superintendent, two foremen, two assistant foremen, and forty-six men, whose ordinary duties are the laying down, overhauling and repairing the moorings in the Port of London; and the whole of this staff is available for immediate service in wreck-raising, the number of men being augmented, when necessary, by the temporary engagement of as many other hands as may be required for the work.

The following is a short description of the mode of dealing with a sunken vessel; it is the duty of the Harbour Master of the district in which a casualty occurs, to report it immediately by telegraph to the head office and to Lloyd's, and to send a watch-boat to take up a position as nearly as possible over the wreck. This boat flies a green flag with the word "Wreck" in white letters by day, and displays two bright lights placed horizontally by night. In the case of very long vessels, two watch-boats are provided, one moored at the head and the other at the stern. Notices are also issued stating the position of the wreck, for the information of pilots and of persons in charge of craft navigating the river. At the low-water following the sinking of the vessel, the lighters are brought down and preparations are commenced for slinging her. It is first of all necessary to cut away any of the masts or rigging which would be likely to interfere with the operations. The lighters are then laid alongside the wreck, and the wire-ropes are passed under and adjusted with the aid of the steam-winches and tugs. It is frequently necessary to employ divers to assist in this operation, and where the wreck is deeply embedded in mud or sand, a force-pump is used to wash out a hole at the place where it is desired to pass the rope. The adjustment of the ropes, which vary in number from eight to fourteen according to the weight of the vessel to be lifted, generally occupies from four to eight tides. The position of the lighters with regard to the wreck is governed by circumstances. When the depth of water is sufficient they can be placed directly over the vessel to be lifted; when the water is shallow they have to be placed at the sides. The operation of lifting the wreck is generally arranged to take place during spring tides, as the extra height to which the water then rises enables the wreck to be placed further in shore, and the lower level to which it ebbs facilitates the work of stopping any holes or openings which may have to be

closed up before the pumping out of the water can be accomplished. At low water of the tide preceding the flood chosen for the lift the slack of the ropes is hauled in, and the latter are securely fastened either in the nippers or by lashings through the eye-holes at the ends. Two or three tugs are then made fast to the lighters, and, as soon as the rising tide has lifted the wreck off the bottom, the lighters are gradually towed towards the shore until the time of high water, the wreck being just clear of the bottom.

As the rise of an ordinary spring tide in the Thames is about 20 feet, the wreck will then rest some 12 or 13 feet nearer the surface than at the previous tide, the 7 or 8 feet lost being due to the difference in draught of the lighters when weighted, and to a certain amount of give in the ropes when the full strain is brought upon them. As the tide falls, the ropes are relieved of the weight, and the lighters are towed clear of the wreck to avoid fouling. The same process has to be gone through two or three times, according to the depth from which the sunken vessel has to be raised. When the wreck has been brought so far in shore that her decks are clear at low water, the work of stopping all leaks and openings is proceeded with. If there be a hole in the plates, as is usually the case, this is closed by a shield, made either of timber or iron as may be the most convenient. This shield is bolted to the sound plates by divers, who also close any port-holes or hatchways under the water-level. The steam-pumps are then put to work, and, the water being pumped out, the vessel floats and is taken into dock. The time occupied in raising a large steamer varies under favourable circumstances from a week to a fortnight from the commencement of the operations.

The cost is regulated by a fixed scale of charges for the use of the lighters and other craft and materials employed, and the payment of the amount actually expended in labour.

During the past eleven years, seventy-four steamers of 55,758 tons register, fifty-four sailing vessels of 9,128 tons, and three hundred and one barges of 11,956 tons, being a total of 76,842 tons register of shipping, have been raised by the Conservancy lighters.

The Paper is accompanied by tracings from which the *Figs.* in the text have been prepared.

Discussion.

Mr. HARRISON HAYTER, President, said that a short Paper had Mr. Hayter. been purposely selected to occupy the last meeting of the Session. Although short, however, the Paper was complete. It was descriptive and useful, and it had been presented by the engineer of the Thames Conservancy, whose extensive experience in wreck-raising could not fail to be of great value. The Paper added to the variety of the subjects that had been before the Institution during the present Session. When it was about half over, he had directed attention to the great variety of engineering subjects that had even then been dealt with. Their number had since been increased, and, indeed, there were few branches of the profession that had not received some attention during the Session. It was desirable that such variety should be promoted, so that all branches of engineering might, in their turn, be considered, in order to maintain the representative character of the Institution. He was sure that it would be the desire of the members to tender their hearty thanks to the Author.

Admiral Sir F. NICOLSON, Bart., observed that among the many Admiral Sir F. Nicolson. operations of the Thames Conservancy he had always regarded wreck-raising as one of the most successful. He attributed it not merely to the plant which the engineers had provided, but to the good fortune of the Conservators in having at the head of the mooring-service Mr. Wood, a man who seemed to have a peculiar aptitude for raising vessels. Whenever a vessel had been sunk—whether at Antwerp or at Sheerness—on one occasion he had been sent to watch the operations of raising a war-vessel at the Isle of Wight—Admiral Nicolson had always been struck with the aptness displayed by Mr. Wood in manipulating the plant which had been described in the Paper, and with the extreme rapidity with which the vessels had been raised. With reference to one question mentioned by the Author—not an engineering question in any sense, but one of great importance—he might mention that, previous to the Act of 1870, the Conservancy had no legal powers to raise vessels. They had to wait until the owners or the underwriters or someone else endeavoured to raise them. He remembered that one vessel remained in Woolwich Reach obstructing the navigation for more than a year. At present, by a short Clause in the Act of 1870, it was left in

Admiral Sir F. Nicolson. the discretion of the Conservators to say whether any vessel ought to be raised. It enabled them to say, as they always did, that the vessel must be raised at once; and the result was that the work was taken in hand before she became filled with silt or sand, and before the operations became more expensive and difficult. He thought it was of the greatest importance that all Harbour Authorities should have that discretionary power, so that the moment a vessel was sunk she could, if the necessary plant was available, be raised at once.

Mr. Halpin. Mr. DRUITT HALPIN hardly thought it advantageous to have the whole of the plant of the nature shown by *Figs. 1 and 2*. There was another form of plant to which he would allude, originally designed by Sir Edward Harland, of Belfast, who used it in raising a large vessel named the "Wolf," which was sunk in Belfast Harbour. The merit of that plant was that there were separate pontoons or barges which were held rigidly apart by girders. In that way the plant never grounded on the wreck, and the masts and all obstructions were cut away, the cross-girders were then brought right on the wreck, and so a great part of the lift was utilized. With regard to the length of lift that could be obtained, the range of the tide seemed to determine that; and it was stated that 7 or 8 feet was lost by slack ropes, and not that merely, but also the immersion due to the load lifted.¹

Mr. Allen. Mr. W. H. ALLEN remarked that his experience in salvage operations lay in the manufacture of centrifugal pumps for that purpose—an important part of the arrangement. For many years they were constructed in the ordinary way with steel working parts; but, as the machinery was frequently submerged in bad weather, it was found that the oxidation of the working parts prevented operations from being continued immediately afterwards. In consequence the engines had to be taken to pieces and a great deal of time was thus lost. It was then suggested that the working parts should be made of manganese-bronze, which had been adopted with considerable success. The result was that the engines might now be submerged for any length of time, and immediately the tide receded and the weather abated, they could be started. He placed on the table a set of the parts that his firm had in hand for some of the salvage companies, which all spoke in terms of high praise of the modification that he had alluded to.

¹ For a description of this apparatus *vide* Proc. Inst. Mech. Eng., 1878, pp. 116 *et seq.*

Mr. R. R. TUTHILL referred to operations conducted by him under Mr. Tuthill. peculiar difficulties upon several wrecks on the African coast for the Cape Government, plant having to be made on the spot for the purpose. The plant described by the Author was a perfect class of machinery; but the difficulty in distant parts of the world was to get the necessary materials and then to apply them. Reference had been made to the difficulty of getting ropes or chains under vessels. That was a difficulty that had always been experienced; but there was a plan by which it was possible to place a sling round a wreck, in the same way as masons practised what was called "jack-slinging" with heavy stones. The wrecks on the African coast to which he had referred were two iron tug-boats sunk in a very exposed situation, and also timber vessels. They were destroyed in sections by dynamite, and each part was lifted separately. The divers employed were ship-carpenters, who, knowing the structure of the vessels, were able to take away the beams and everything of that kind, lifting them as they were broken away by the dynamite. He had also raised a launch that was upset at East London. She turned over, and lay imbedded in the sand, so that it was impossible to get anything under her. She had therefore to be slung partly in the manner he had mentioned. He had used steel-wire rope on several occasions, and had found them very easy to apply. But if strained nearly to the breaking-point, they became rather dangerous; the wires started out and the men could not handle them. Bullivant wire-ropes were used and answered well. The nippers required a great deal of care; the ropes if used for any length of time became slippery by stretching and consequent smoothness of surface, and the nippers did not hold as well as might be desired. With regard to the closing of rents and holes, there was a method which he had seen used on one occasion with a vessel in the bottom of which were two or three rents. It was suggested that two or three sides of bacon should be put over the holes. That was done, and they were secured by struts and wedges, the vessel was pumped out, and for three months afterwards she carried on the trade of the port. He afterwards went down to see whether it was a fact, and saw the bacon taken away, and the mate claimed it. It was a ready way of dealing with a ragged hole, as would be evident to every one who knew what took place under such circumstances in an iron vessel. One wreck that was down in the river for 22 years was of a timber paddle-vessel. The upper works were gone, and she was almost entirely buried in sand and silt. After it had been decided to remove her, the

Mr. Tuthill. boiler and fittings were taken out by degrees. Among other things, her chain cables were taken away, which were corroded something like $\frac{3}{8}$ inch deep; but attached to them was a stopper made of coir rope, as sound as on the day it went out of the manufactory. Some matting made of coir was also picked up, which was perfectly sound, and he had used it in his office for many years afterwards. That showed the great length of time that coir would exist under water, even in that climate. It was to be observed that in such "destructive" removal of wrecks, dynamite and similar explosives were preferably employed upon iron, and gunpowder upon wooden vessels—the latter explosive detaching portions of the wreck which floated and were so secured, but dynamite cutting iron by the energy of its local action.

Captain Ward. Captain C. Y. WARD, I.N., said that his chief connection with the subject of the Paper had been in regard to inquiring into the causes of shipwreck, not into the raising of wrecks. Many years ago he had some experience of wreck-salving, and it appeared to him that for raising vessels in still waters, nothing could be better than the method described in the Paper.

Sir Frederick
Bramwell.

Sir FREDERICK BRAMWELL, Past President, inferred from the drawings that the circles—he did not think they were pulleys—over which the ropes passed, were somewhat small, having regard to the diameter of the ropes, assuming that they were to scale, and he presumed that the large sections might be so taken. But he imagined—although there had been no description of it—that the ropes were never moved over these circles when they were subjected to stress; but that they were simply placed in their positions before the stress was applied, and that they were then not required to traverse; otherwise it seemed to him that the curves were not of sufficient dimensions for the purpose. With regard to the rope itself, if the piece on the table was to be regarded as a sample, it was laid in the old-fashioned manner, in which the wires on the outside were parallel to the general axis of the rope; therefore, when the rope was bent, the wires were in the direction which resisted the bend—that was, they were parallel on the outside to the line of the rope; whereas, if they were laid in the reverse way—and there was a great deal of wire-cable made in that manner in the present day—the parallel lines were in the interior of the rope, while the wires on the outside, instead of being parallel, lay at a considerable angle. The result was, that a rope of that character could be bent with great readiness as compared with a rope like that exhibited. He had seen colliery ropes which had worn away not by the

starting out of wires, as had been explained, when ropes of the character of that on the table had been overstrained, but by the attrition of the pulleys over which they had passed; and they looked like a flexible bar of iron or steel rather than a rope. He should be glad to know whether there was any objection to a rope laid in the other way, except in regard to splicing, which he believed was said to be much more difficult than with a rope like that on the table.

Sir Frederick Bramwell.

Mr. W. P. BULLIVANT had not intended to take part in the discussion, but, after the remarks of Sir Frederick Bramwell, advocating what was commonly known in the trade as the Lang lay, he might be permitted to give some explanation as to why the rope on the table was so made. He would only say that, so far as the rope on the table was concerned, the Thames Conservancy had been using it for nearly twenty years, and Mr. More would bear him out in saying that it had given satisfactory results. It was meant to resist the effects of rust rather than those of friction, and it was closed in the reverse way to that in which the strands were laid, because a rope so made was much easier to splice, repair, and handle. A rope made in the same way as that in which the strands were laid was very liable to kink; but if made in the reverse way, the tendency was to throw itself out of a kink. He therefore thought that, in that instance, and in most instances other than for quick running (as in the case of a colliery hauling-rope or a cable-tramway rope), it was more advantageous to close the rope in what Sir Frederick Bramwell had called the old way; but the original way of closing ropes was in the same way as the strands were laid. (Sir FREDERICK BRAMWELL: Hemp ropes.) Wire-ropes too. At Jermyn Street, ropes made as far back as 1838 might be found closed in that way. In regard to the general question of the salvage of ships, he had considerable experience. It was stated in the Paper that the raising of sunken vessels was an important duty devolving on Conservancy Boards and other Harbour Authorities. In that he perfectly agreed, but he wished to point out that the only Harbour Authority that had realized that duty was the Thames Conservancy. It was the only authority in the country that had any regular and efficient raising-appliances. On the Mersey it was the custom to destroy wrecks by means of explosives. There was no public authority in the world which had appliances for dealing with sunken vessels of large size, and he might go farther and say that there were only three associations which possessed efficient plant. The contract for raising the wreck of the "Sultan" was given to an Italian firm, and that for raising

Mr. Bullivant.

Mr. Bullivant. the "Howe," was given to the Neptune Company of Stockholm. In England, notwithstanding the vast proportion of shipping under its flag, there was not sufficient plant outside the Thames Conservancy to raise a vessel of 500 tons. The three companies to which he referred were the Schwitzer Company of Copenhagen, the Neptune Company of Stockholm, and the Northern Company of Hamburg, the last being a new one. There were only two practical methods of raising vessels,—one by pumping and the other by camels. The camels such as those shown in the illustrations could be used where there was considerable rise and fall of tide. The pumping method had to be resorted to in such waters as the Baltic, where the Schwitzer and the Neptune Companies conducted their operations. The Neptune Company had a particularly favourable case in raising the "Howe," although they had too small a price for the work. What was wanted in this country was some central authority to promote or subsidise an arrangement for having salvage craft round the coast. It was on such a principle that the Northern Company of Hamburg was started. It had a subsidy from the Authority of the Elbe for keeping the river clear. With reference to lifting by camels, he might mention that a few years ago an interesting case came under his notice. It was interesting to him, not only because, in conjunction with Mr. Charles Wood, he had something to do with the operations, but because he derived considerable profit from the enterprise. The wreck was that of a vessel named the "Locksley Hall," of about 2,200 tons register, laden with wheat. Mr. Wood had calculated that there was about 1,800 tons dead weight to be lifted. To show how quickly such undertakings could be accomplished, he might state that four old hulks were bought, some 9-inch steel-wire ropes and clips were made and put round the vessel, and she was lifted in that way—the result being that the small syndicate concerned in the affair received a dividend of 187½ per cent. in six weeks. In the ordinary course the vessel would have been blown up. The Mersey Docks and Harbour Board wished to destroy her, but she happened to go down over the Mersey Tunnel, and the Tunnel authorities naturally objected to such operations there. The vessel was sunk in February, and in the following June tenders to lift her were advertised for. The syndicate offered to lift the vessel for £20,000. The Mersey Docks and Harbour Board declined to give that amount, but they gave £15,000, and the net profit on the undertaking was £10,800. That was an illustration showing that, with a little enterprise, there was plenty of money to be made out of wreck-raising. It was only fair, however, that he

should say something on the other side of the question. In the case of the Mersey Docks and Harbour Board, the dealings were with a body that could pay the money; and it was imperative that the vessel should be got out of the way. He might be permitted to refer to an instance illustrating the difficulty of dealing with salvage matters. He referred to the case of the "Eider," stranded off the Isle of Wight. The Northern Company of Hamburg and the Neptune Company of Stockholm combined to raise the vessel; and the terms of the agreement were that they should be paid 50 per cent. of the salvage-value to be awarded by an arbitrator. The arbitrator awarded between £50,000 and £60,000; but when the vessel came to be put up at auction, she was sold for £8,000. The North German Lloyd Company desired to pay the salvage company only 50 per cent. of the £8,000, and in default of that they offered the vessel. That was often the case—when a vessel was salvaged it had to be taken instead of the money. The value of a salvaged vessel was a very problematical item. In the case of the "Locksley Hall," for raising which the Mersey Docks and Harbour Board paid £15,000, when put up to auction she realised £1,000; so that if the contractors had taken the vessel instead of the money, they would have lost heavily.

Mr. A. GILES, Vice-President, was pleased to find that the Conservators of the Thames had the power to remove any wrecks that occurred in the river; but when he found their lifting-power was only 2,150 tons, he did not think it sufficient for the purpose. There were many vessels exceeding 3000 tons, and much greater lifting-power was therefore needed to get them out of the way. With reference to the "Eider," he was one of the arbitrators and knew something about the case; and he would caution any gentlemen who might be interested in salvage operations, to use great care in making their agreements. In the case of the "Eider," the two companies undertook to raise the wreck and bring it safe into port on being allowed 50 per cent. of the value of the vessel when salvaged. That was all very well, but the difficulty was to arrive at that value. He had a gentleman with him who was competent to estimate the value of the repairs to the ship and engines. He also independently estimated the value of the ship, taking her original cost and considering the amount of depreciation, also the cost of the repairs that would be required to put her in the condition she was in before being wrecked. That was the view that the salvors had of the value of the ship, but the English and the German arbitrators were so widely apart in their estimates that he said to one of the German arbitrators:

Mr. Giles. "How is it that your estimate for repairs is so much less than ours? I had the opinion of a very able mechanical engineer, a shipbuilder and an engine-maker, who have gone carefully into every cost of making the ship as good as she was before she was wrecked, how is it you do the work for so much less than we can do it for in England? What do you pay your men in Hamburg?" The reply was, "3s. 6d. or 4s. 6d. a day." Mr. Giles then asked how long the men worked, and the German arbitrator replied, "From twelve to fourteen hours a day." The secret was out. In England men were paid 5s. or 6s. or 7s. per day as mechanics, and worked only eight or nine hours. It was, therefore, easy to understand why the Germans could work so much more cheaply. That was an illustration of English workpeople driving trade out of the country by their excessive demands.

Mr. More. Mr. CHARLES J. MORE, in reply, said that the cost of raising vessels in the Thames was greatly influenced by the circumstances in which the wreck took place, the weather, the depth of the water, the position of the vessel, and the nature of the cargo. He found by calculation in the case of a number of vessels averaging 883 tons register, that the cost was £1,040 per vessel, or about 23s. 6d. per ton register. The least expensive was a vessel of 924 tons, which only cost £330, or 7s. 2d. per ton, to raise. The most expensive was a vessel of 1,100 tons, the raising of which cost 49s. per ton. The figures would show that they had no opportunity of making large profits like those mentioned by Mr. Bullivant. Reference had been made to the superiority of the joint camels over those used in the Thames. He thought, however, that the latter type was much the more handy, and it had been always found to work satisfactorily. In a place where there was no great lift of tide, the method alluded to by Mr. Halpin might be employed with advantage where the lighters could be filled and pumped out again. No difficulty had ever been found in raising any wreck in the Thames with the plant described. With reference to the statement of Mr. Giles that the lifting power was only a little over 2,000 tons, he might mention that larger vessels, owing to their superior construction, could be kept afloat until they were got ashore; and then it merely became a question of pumping, absolute lifting not being required. With reference to wire ropes, those which had been supplied by Mr. Bullivant had always been found to work satisfactorily, and had lasted well, care being taken to keep them in good order. The same remark applied to the nippers; if care was exercised, there was very little slip. Sir Frederick Bramwell was right in stating that there was no pulling of the ropes after

they went round the bollards, which were merely intended to keep Mr. More. them in position, so that there should be no strain, as there would be if they were hauled in afterwards. What Mr. Bullivant had stated as to the condition of wreck-raising apparatus in this country was not creditable to a great maritime nation, viz., that, with the exception of that on the Thames, there was no plant in any part of the kingdom capable of lifting a 500-ton vessel. He thought that it would be worth while for some company, aided perhaps by the insurance companies, to provide plant which could be sent out, not only to clear navigable channels, which was a work of great importance, but also to save a number of valuable vessels which were now blown up instead of being restored to useful work as they might be.

Correspondence.

Mr. JOHN HAYES observed that it was well to bear in mind that Mr. Hayes. the risks attending the raising of wrecks and of salvage operations generally were great, depending largely upon "the locality," whether in still or in exposed waters, and also upon the depth of water over the wreck. Another point to be borne in mind was that it was far better to have salvage plant built on the river or on the coast where it was likely to be eventually used, irrespective of any slight consequent increase in first cost for construction and equipment. Some years ago, a case in point came under his observation—his services having been requisitioned at a late hour to inspect and report upon some pontoons and wreck-raising plant then lying at Barrow-in-Furness, although they were intended for service in the river Thames. When completed this plant was useless, owing to the outlay and risk attendant upon bringing or towing it to London; and he believed that, without ever having been used, it was, after lying at the makers' works at Barrow-in-Furness for several years, cut up and sold as scrap. The proprietor had here entered into a business of which he had no experience, and was, no doubt, induced to have his plant built at Barrow, because both labour and materials were less costly there than on the Thames, losing sight of the fact of its ultimate destination. Another case within his experience was that of the "Florence Nightingale," a sailing vessel of considerable tonnage, loaded with grain, which was wrecked off the French coast. A Liverpool syndicate that undertook the salvage of this vessel purchased a powerful Gwynne centrifugal pump, and at considerable cost hired a portable engine

Mr. Hayes. which was set to work on the deck of the vessel; but after some months occupied in abortive operations, carried on at much expense, the business ended by a sudden storm washing the portable engine and pump overboard, and the wreck itself going to pieces. In this instance, the risks were too great, owing to the exposed position of the ship, and the operations having to be carried on at a considerable distance from home. One of the principal reasons why the Mersey Docks and Harbour Board preferred to clear wrecks out of the way by means of explosives rather than to "salve" them in the usual way, was that the former was the more expeditious course, having regard to the strong currents prevalent in the Mersey.

Lieut. Sweny. Lieut. M. SWENY, I.N., mentioned that in connection with the work of raising wrecks within the port of Liverpool, the Mersey Docks and Harbour Board had two iron "lumps" and two iron "camels." Their dimensions were as follows :

—	Lumps.		Camels.	
	Ft.	Ins.	Ft.	Ins.
Length . . .	72	0	74	0
Breadth . . .	25	0	15	6
Depth . . .	10	6	8	6

Their aggregate lifting-power was about 700 tons. When any need existed for raising sunken vessels of larger tonnage, this plant was augmented by adapting old vessels specially for that work. He used 8-inch steel-wire hawsers for lifting wrecks, and adjusted them by sweeping their bight under each end of the vessel to be raised, with the assistance of steam-tugs. After they were placed under the wreck, a diver was sent down to report. At times, instead of sweeping the wreck with the wire-hawsers, it was necessary, if the sunken craft was bearing heavily on the ground, to bore holes under the keel at suitable intervals to reeve light chains through, and therewith to draw the wire-hawser under. Eight or ten of these hawsers might be necessary when the four lifting-vessels were in use, and their lengths in practice varied from 30 to 55 fathoms each, according to the depth of water in which the wreck lay. If a cargo barge or flat was sunk in one of the docks where there was no room for sweeping her with wire-ropes, 1½-inch close-link chains were used to raise her. He would add that when a wreck lay in deep water, a neap tide

was chosen for the first lift. The wreck, once fairly slung by the wire-ropes to the lifting vessels, was towed in towards the beach and landed as high up as the tide at high-water would allow. Another lift was probably rendered desirable at the following high-water, and then she was left until spring tide, when she was beached at high-water as high as possible. At low-water the wreck was examined, and steps were taken to repair her or to break her up as might be advisable.

At the conclusion of the ordinary business of the meeting, the President and Council held the fifth Monthly Reception of the Session.

23 May, 1893.

This being the Tuesday in Whitsun week, there was no meeting.

LIST OF MODELS AND APPARATUS

EXHIBITED AT THE MONTHLY RECEPTION, 16 MAY, 1893.

Exhibitor.	Objects.
W. H. ALLEN & Co. . . .	Appliances, to prevent oxidation in pumping-engines used in salvage work.
Prof. T. HUDSON BEARE, B.Sc., M. Inst. C.E.	Calorimeter and accessories. Cement-testing machine and plant. Automatic stress strain-gear. Extension strain-gear. Stone strain-gear. Torsion strain-gear.
JOHN BROWNING	Binoculars with specimens.
BULLIVANT & Co. . . .	Wire cable.
Prof. D. S. CAPPER, M.A., Assoc. M. Inst. C.E.	Apparatus for the measurement of the deflection of beams. Apparatus for the measurement of the stress in lattice-girders.
L. P. CASELLA	Air-meter. Pocket altazimuth. Goad's geodetic altazimuth. Pocket aneroid for measuring heights, &c. Prismatic compass. Improved current-meter. Inverted pendulum. Transit theodolite. Travellers' transit theodolite. Water-testing apparatus.
CHARLES CHURCHILL & Co. .	Small apparatus and tools for use in engineering laboratories.
THOMAS CLARKSON, Wh.Sc., Assoc. M. Inst. C.E.	Model of sampler for ores, fluids, &c.
CROSBY STEAM-GAGE AND VALVE COMPANY	Indicators (2).
BRYAN DONKIN, Jun., M. Inst. C.E.	Small cylinders (3).
ELLIOTT BROTHERS	Direct-reading decimal gauge. Self-recording volt-meter. Steam-engine indicator.
Prof. J. A. EWING, F.R.S., M. Inst. C.E.	Two examples of magnetic curve-tracer for examining the magnetic qualities of metals. Instrument for the graphic determination of the greatest bending-moment and shearing-force under the passage of a typical train.
Prof. T. CLAXTON FIDLER, M. Inst. C.E.	Model and photograph of 5-centred arch. Photograph of models illustrating the deflection-curve of beams.

Exhibitor.	Objects.
Prof. T. CLAXTON FIDLER— <i>continued.</i>	Photograph of stereographic model illustrating the relations of temperature, pressure and volume. Photograph of apparatus devised for investigating the vibrations of loaded shafts. Photograph of figures described on smoked glass by the vibrations of loaded shafts. Photograph of experimental compound-engine. Photograph of "Wicksteed" testing-machine.
HENRY FLETCHER, SON AND FEARNALL.	Photographs (24) illustrating the effects of collisions of vessels.
Colonel A. J. FRASER, R.E. (per Elliott Brothers).	New form of polar level.
GLOBE ENGINEERING COMPANY	Calorimeter and fittings.
Prof. JOHN GOODMAN, Wh.Sc., Assoc. M. Inst. C.E.	Automatic cement-setter.
	Averaging instrument for measuring the mean heights of indicator-diagrams.
	Planimeter.
JOHN GWYNNE, M. Inst. C.E.	Photographs of salvage-plant.
Prof. O. HENRICI, F.R.S.	Calculating-machine (new method).
	Harmonic analyser (new form).
	Model showing the double generation of epicycloids.
	Pantograph (by Coradi of Zürich).
J. J. HICKS.	Air-meters.
	"Biram" anemometer.
	Hydrometers (2).
Prof. D. E. HUGHES, F.R.S.	"Hughes" induction-balance.
Prof. A. JAMIESON, F.R.S.E., M. Inst. C.E.	"D'Arsonval" galvanometer.
	Simple galvanometer.
	"Oersted" stand and other apparatus.
Prof. ALEX. B. W. KENNEDY, F.R.S., M. Inst. C.E.	Apparatus for measuring the extensions of bars within the limits of elasticity.
CHARLES J. MORE, M. Inst. C.E.	Model of 400-ton lifting-lighter used by the Thames Conservancy.
NALDER BROS. & Co. . . .	Ammeters and voltmeters.
	"Ayrton and Perry" variable standard of self-induction.
	Ballistic galvanometer.
	"Carhart-Clark" standard cell.
	Professor Ewing's magnetic curve-tracer.
	Megohm with sub-divisions.
	Resistance-coils (dial and post-office patterns).
	Standard potentiometer.
	"Thomson" reflecting astatic galvanometer.
	Wheatstone bridge.
Prof. JOHN PERRY, F.R.S., Assoc. M. Inst. C.E.	Apparatus from the Mechanical Laboratory of the Technical College, Finsbury, to illustrate Professor Perry's method of teaching.
Professor W. RIFFER . . .	Model of the "Sulzer" valve-gear.
SIEBE, GORMAN & Co. . .	Drawing of a pontoon.
	Model of air-bag or caisson used for salvage purposes.

Exhibitor.	Objects.
WILLIAM F. STANLEY . . .	Aluminium level. Level with "Stanley-Hoffmann" head. Aneroid barometer. Mine-staff. Pocket case of drawing instruments. Slide-rule (Fuller & Bakewell's). Tacheometrical staff. Telemetrical mining theodolite.
J. H. STEWARD	"Abney" level (improved). "Blakesley-Steward" semi-circle or double-reflecting sextant. "Dredge-Steward" omni-telemeter. "Francis" surveying instrument. Sight and alidade for plane-table. Major Belfield's luminous compass. Major Verner's military sketching and luminous compass; and traversing-pencil. Metriangle—a portable combined angle-measurer and plotter, patented by Captain A. H. Kenney-Herbert and Captain A. F. Gatliff.
Prof. W. C. UNWIN, F.R.S., M. Inst. C.E.	"Barrus" calorimeter. Deflection-gauge. Micrometer. Roller and mirror measuring to $\frac{1}{100.000}$ th of an inch. Spherical joints for crushing- and tension-experiments. Stone and brick tested by crushing. Torsion-micrometer. "Wöhler" test-bars.
J. W. WILSON, Jun., Assoc. M. Inst. C.E.	Multicellular electrostatic voltmeter. Reflecting galvanometer. Standard deka-ampere balance.

ANNUAL GENERAL MEETING.

30 May, 1893.

HARRISON HAYTER, President,
in the Chair.

The Notice convening the Meeting was taken as read, as well as the Minutes of the Annual General Meeting of the 31st of May, 1892, which the President was authorized to sign.

The following proposal having been read :—

H.R.H. Prince George Frederick Ernest Albert, Duke of York, K.G., Commander R.N., *as an Honorary Member.*

It was moved by the President, seconded by Mr. Giles, the senior Vice-President, and

Resolved—That the Standing Orders in Section III, Clauses 2 and 3 of the By-laws, respecting the mode of election by ballot, be suspended in the case of H.R.H. the Duke of York, whereupon

His Royal Highness was elected by acclamation an Honorary Member.

It was moved, seconded, and resolved,—That Messrs. J. Angus, Geo. W. Higham, A. C. Hurtzig, James P. Maginnis, C. S. T. Molecey, W. F. Pettigrew, James F. Reade, T. Frame Thomson, Edwin J. White, and L. S. Zachariasen, be requested to act as Scrutineers for the election of a President, of four Vice-Presidents, and of fifteen Other Members of Council for the ensuing year ; and that, in order to facilitate their labours, the Ballot-papers be removed for examination at intervals during the time the election remained open.

The Ballot having been declared open at ten minutes past eight, the Report of the Council upon the Proceedings of the Institution during the Session 1892–93 (p. 205) was read, the Statement of Accounts being taken as read. After discussion it was

Resolved—That the Report of the Council be received and approved, and that it be printed in the “Minutes of Proceedings.”

The Ballot was then declared to be closed, having been open more than one hour.

Resolved—That the thanks of the Institution be tendered to the Vice-Presidents and other Members of Council for the assistance they had rendered in promoting its objects.

Mr. Giles, the senior Vice-President, replied on behalf of himself and his colleagues.

Resolved unanimously—That the members present at this meeting desire, on behalf of themselves and others, to place on record their high appreciation of the services rendered to the Institution by Mr. Harrison Hayter, President, during his year of office.

Mr. Harrison Hayter, President, returned thanks.

Resolved,—That Messrs. Frank Stuart Courtney and Samuel Hanna be thanked for the time and trouble they had bestowed in auditing the Accounts for the past financial year; and that Messrs. Samuel Hanna and Francis Fox (of Westminster) be requested to act as Auditors for the ensuing twelve months.

Mr. Hanna replied on behalf of himself and Mr. Courtney.

Resolved,—That the thanks of the meeting be given to Dr. Pole, Honorary Secretary, to Mr. Forrest, Secretary, and to the members of the staff, for the admirable manner in which they had conducted the business of the Institution during the past year.

Dr. Pole and Mr. Turner (Mr. Forrest being absent from indisposition) expressed their acknowledgments.

The Scrutineers then reported the election of:—

President.

ALFRED GILES.

Vice-Presidents.

Sir Robert Rawlinson, K.C.B.	Sir James Nicholas Douglass,
Sir Benjamin Baker, K.C.M.G.,	F.R.S.
LL.D., F.R.S.	John Wolfe Barry.

Other Members of Council.

William Anderson, D.C.L.,	James Mansergh.
F.R.S.	Sir Guilford Molesworth,
Alexander R. Binnie.	K.C.I.E.
Sir Douglas Fox.	William Henry Preece, F.R.S.
Sir Charles Hartley, K.C.M.G.	Sir Edward James Reed, K.C.B.,
J. C. Hawkshaw, M.A.	F.R.S., M.P.
Charles Hawksley.	William Shelford.
Alexander Blackie William	Francis William Webb.
Kennedy, F.R.S.	William Henry White, C.B.,
Sir Bradford Leslie, K.C.I.E.	LL.D., F.R.S.

Resolved,—That the thanks of the meeting be given to the Scrutineers, and that the Ballot-Papers be destroyed.

REPORT OF THE COUNCIL, SESSION 1892-93.

THIS Annual General Meeting of Corporate Members is convened for two objects—to receive the Report of the outgoing Council and to elect its successors for the ensuing year. In order that the first of these objects may be fulfilled the Council begs to present the following Report as to the state of the Institution during the past year.

THE ROLL OF THE INSTITUTION.

The number of members of all classes elected during the year ending the 31st of March, 1893, was 344; and during the same period there disappeared from the list—by death, resignation or erasure—137 names. The net increase was, therefore, 207, or at the rate of $3\frac{1}{2}$ per cent. per annum.

Complete details are given in the tabular statement printed below and the Council is glad to draw attention to the fact that

	April 1, 1891 to March 31, 1892.					April 1, 1892 to March 31, 1893.				
	Honorary Members.	Members.	Associate Members.	Associates.	Totals.	Honorary Members.	Members.	Associate Members.	Associates.	Totals.
Numbers at commencement . . .	20	1,743	2,965	422	5,150	18	1,774	3,177	402	5,371
Transferred to Members	..	59	59	..		..	43	43	..	
Transferred to Associate Members .	..	..	..	..		..	..	2	2	
Elections .	3	28	324	7	366	..	33	306	4	344
Restored to Register .	..	..	4	..		..	..	1	..	
Elected Honorary Member .	..	..	..	1		..	..	..	..	
Associate elected Member .	..	..	..	1	145	..	..	..	1	
Deaths .	5	40	27	13	221	3	30	21	13	137
Resignations .	..	6	10	10		..	11	24	11	
Erased .	..	10	20	2		..	..	21	3	
Numbers at termination	18	1,774	3,177	402	5,371	15	1,810	3,377	376	5,578

out of 306 Associate Members elected during the year, 106 were drawn from the Student class.

In the list of deceases the Council records with regret the names of three Honorary Members—Lord Bramwell, Dr. Werner von Siemens and the Duke of Sutherland; of its esteemed Past-President, Sir James Brunlees; of two distinguished Members, Alexander Carnegie Kirk, LL.D., and Peter William Willans; and of two Associates, who had long occupied prominent positions in the railway world, Sir James Allport and Sir George Findlay. Sir James Brunlees was a man who by sheer ability and force of character raised himself to the front rank of the profession, attaining the office of President of the Institution in 1883 and receiving the honour of knighthood on the completion of the Mersey Tunnel. Dr. Werner von Siemens was the head of a family which has become famous in scientific circles all over the world. Four members of this distinguished family have been connected with the Institution. Of these the ever-lamented Sir William Siemens, who became a naturalized Englishman, achieved a reputation in all respects analogous to that of his elder brother whose loss is now deplored. The numbers on the books on the 31st of March, 1893, were 5,578, as against 5,371 at the corresponding date last year; or, including Students, 6,397 and 6,239 respectively. Turning to the List of Members, it will be noticed that for the first time distinguishing letters have been affixed to the names of all who have contributed Papers published in the Minutes of Proceedings and who have obtained Medals or Premiums, thus—

(†) prefixed to a name indicates the contributor of a Paper published in the Minutes of Proceedings.

(T)	"	"	"	award of a Telford Medal.
(t)	"	"	"	" Telford Premium.
(W)	"	"	"	" Watt Medal.
(S)	"	"	"	" George Stephenson Medal
(M)	"	"	"	" Miller Scholarship.
(m)	"	"	"	" Miller Prize.
(m)	"	"	"	" Manby Premium.
(H)	"	"	"	" Howard Quinquennial Prize.
(L)	"	"	"	deliverer of one of the Special Series of Lectures.
(F)	"	"	"	deliverer of a James Forrest Lecture.
(*)	"	"	"	a former Student.

It should be stated that Members of Council and Honorary Councillors are not eligible for Medals or Premiums.

From the following Table it will be seen that, of those now

on the books of the Institution, 528 members of all classes, excluding Students, or $9\frac{1}{2}$ per cent., have contributed Papers to the Proceedings:—

—	†	T	t	W	S	M	m	m	H	L
Honorary Members	3	2	1	..	..	..	..	..	1	2
Members	346	78	149	32	6	2	21	24	1	11
Associate Members	147	10	24	4	2	7	71	4		
Associates	32	16	11	..	..	..	1	1	..	1
Students	5	..	..	..	..	..	8			
Totals	533	106	185	36	8	9	101	29	2	14

The deceases were :—

Honorary Members.—Lord Bramwell, F.R.S.; Dr. Werner von Siemens; and the Duke of Sutherland, K.G.

Members.—John Bailey; John Blackett; Charles Christison Bone; Sir James Brunlees, F.R.S.E.; Thomas Charles Clarke; Edward Charles Cracknell; Joseph Napoleon Du Barry; William Elliot; James Barry Farrell; James Edward Henry Gordon; John William Grover; Robert Harris; John Richardson Hewitt; George Higgin; Joseph Hindle; Frederick Margaron Hynes; Hodgson Jones; Alexander Carnegie Kirk, LL.D.; Alexander Lavalley; Hermann Ludwig Lange; John Lunt; Henry John Marten; John Hemphill Morant; Perceval Moses Parsons; Henry John Pauling; Richard James Harris Saunders; William Powell Shinn; William Smith (1866); John Hooke Taunton; and Peter William Willans.

Associate Members.—James Alexander Betts; Joseph Julius Cazimajou, B.Sc.; George Howard Clarke; Alfred James Corry; John Douglas; Henry Colthurst Godwin; Andrew Aitken Haddin; Henry Edward Hargreaves; Henry Nicholas Harvey; Edward Hodges; Charles Herbert Hopkinson; George Morgan Lane; Alfred Perry; Charles Remfry; Matthew Henry Simpson; Charles Slagg; William Upton Tinney; Charles Robert Trehwella; Herbert Charles Erskine Vernon; John Richard Hutchinson Williamson; and Guillermo Andres Wilson.

Associates.—Sir James Joseph Allport; Staff-Commander William Edwin Archdeacon, R.N.; Captain Edward Killwick Calver, R.N., F.R.S.; Alfred Carpmel; John Stinson Farmer; Sir George Findlay; Colonel George Edward Grover, R.E.; Major Henry Geffcken Kunhardt, R.E.; Professor John Frederick Main, M.A., D.Sc.; Major-General Henry Spencer Palmer, late R.E.; David Reid; Frederick Charles Rowan; and John Somerville.

The resignations have been :—

Members.—Henry Bawn Addis; Emanuel Allen; William Cochrane; Francis Jellanus Dennys; Willoughby Hannam (*since deceased*); James Marmont; George Wells Owen; William Robinson (Buenos Ayres); George Ebenezer Thomas; Henry Voes; and George Woodbridge.

Associate Members.—Andrew Fawcett Ayre; Horace Allen; Edward Hall

Allies; William Henry Aubrey; Donald Barlow Bain; Willoughby Bazalgette, B.A.; Arthur Horatio Brothers; Samuel Carrington; Charles Brooks Clarke; James David Davies; Charles Robert Bunn De la Salle; William Drake-Brockman; Arthur George Fenn; Henry Chudleigh Granville; Charles Julian Light; Wellwood Maxwell; Louis Neville; Robert Edward Nelson; John Samuel Paine; William Ensor Parry; Frederick Mantell Pratt; Richard Alexander Robinson; Cecil Taylor; and Julius Wiborg.

Associates.—Alexander Aird; Henry Robert Heather Bigg; Captain James Menteith Brebner; Sir John Brown (*since deceased*); Frederick Charles Danvers; James Metcalf Hawkins; Colonel George Lane Cookburn Merewether, B.E.; John Noble; Stuart Rendel, M.A., M.P.; James Honiball Tozer; and Francis Vigers.

ADMISSION OF STUDENTS.

On reference to the Table printed below, it will be seen that the total number of Students on the 31st of March, 1893, was 819, or 49 less than at the corresponding period of last year. During the twelve months under review 165 candidates were admitted and 1 student was restored to the list, while 106 were elected Associate Members and 109 disappeared by reason of resignations, deceases and erasures. The decline in the admissions is due to the strictness with which the Regulations of the Council as to the qualifications of these candidates are enforced. As time goes on, however, these regulations are becoming more generally known, and as the necessary qualifications will in future rarely be wanting, the number of Students should again show an increase. From the foundation of this class in 1867 to the 31st of March, 1893, there have been admitted 3,733 Students, of whom 144 are now Members, 1,367 Associate Members, 8 Associates, and

STUDENTS.

April 1, 1891 . . .	914	April 1, 1892 . . .	868
Admitted during the } year }	200	Admitted during the } year }	165
		Restored	1
			— 166
Elected Associate Mem- } bers }	106	Elected Associate Mem- } bers }	106
Resigned	25	Resigned	14
Deceased	1	Deceased	5
Erased	114	Erased	90
	— 246		— 215
	— 46		— 49
March 31, 1892 . .	868	March 31, 1893 . .	819

819 remain Students, while 1,395 have from various causes ceased to be borne on the books. Of this latter number, however, it may be assumed from past experience that some will apply for election in the immediate or in the more distant future. In any case it is satisfactory to note that nearly two-thirds of the Students admitted since the establishment of the class are still connected with the Institution.

FINANCE.

The revenue of the Institution is derived chiefly from Subscriptions, Dividends and Rents. During the year under review, the receipts on Income Account amounted to £20,854 8s. 6d., an increase of nearly £800 on the previous twelve months. If there be added to this £3,980 0s. 6d. on Capital and £442 10s. 2d. on Trust-Funds Accounts, it will be found that the total receipts amounted to £25,276 19s. 2d. On the other side of the Account the disbursements were:—General Expenditure (including about £7,750 for publications, nearly £650 for repairs and over £250 for legal expenses), £16,527 17s. 6d.; Capital, £8,254 12s. 2d.; and Trust-Funds, £522 2s. 10d.; together £25,304 12s. 6d. The Investments, which have been increased during the year by the purchase of British Railway Debenture Stocks of the nominal or par value of £7,000, now amount, with the various sums held in trust, to £127,006 0s. 10d.

In connection with the Capital and Trust-Funds Accounts, it may be interesting to place on record, that, from 1860—when the Institution was first in a position to make an investment—to the present time, the sum of £42,746 6s. 8d. has been saved from actual Income and transferred to Capital. This represents an average during the thirty-three years of £1,295 6s. 10d. Turning to the Trusts, the following amounts are due to the Institution:—Miller Fund (founded in 1861), £91 2s. 2d.; and Howard Bequest (1873), £26 19s. 5d. On the other hand, the Institution holds the following balances:—Telford Fund (1835), £30 3s. 5d.; Manby Donation (1859), £2 8s. 1d.; Trevithick Memorial (1889), £9 0s. 3d.; Crampton Bequest (1890), £41 2s. 0d.; and James Forrest Lectureship (1892), £23 8s. 0d. The totals are respectively £118 1s. 7d. and £106 1s. 9d., leaving a balance due from the Trust-Funds to the Institution of £11 19s. 10d.

THE SESSION AND MEETINGS.

In CONSTRUCTIVE ENGINEERING four Papers relating to the design, materials of construction and mode of execution of "Graving Docks" were read. They referred to works at Halifax, N.S., at Sydney, N.S.W., at Belfast, and at Newport, Monmouthshire, the authors being the Hon. R. C. Parsons, Mr. E. W. Young, Mr. W. Redfern Kelly and Mr. R. Pickwell respectively. The first two docks were constructed partly of stone and partly of concrete—the former having a wooden floor, whilst the latter had a concrete floor and thus approached in construction the last two, which were entirely of concrete. For the purposes of discussion the four papers were taken together, and in the course of the debate the particulars of other similar works were furnished.

A Paper by Mr. G. E. W. Cruttwell giving an account of "The Foundations of the Two River Piers of the Tower Bridge" should also be noticed. Powers for the construction of this bridge were obtained in 1885 by the Corporation of the City of London, and certain onerous restrictions were imposed to avoid obstruction to the navigation. They are very complex structures owing to their having to accommodate the counterbalance of the opening span with the hydraulic machinery, and the great weight which had to be sustained by these piers rendered an exceptionally wide base necessary. During the construction of the foundations the space was enclosed within wrought-iron caissons, the details of which, with the mode of erecting and of lowering, and of making the excavations, were fully described. The superstructure of the bridge, being still in process of erection, was excluded from consideration.

In the MECHANICAL SECTION several important communications have been brought forward. That which first claims attention was the monograph on further "Steam-Engine Trials" by the late Mr. P. W. Willans. In former Papers the Author submitted the results of trials of a Central-Valve non-condensing Engine; the present communication was devoted to a record of trials with a condensing engine of the same type. Comparing these trials with those made on the non-condensing engine, it was noticed by the Author that—(1) The steam missing at cut-off varied to a somewhat greater extent than it did in the non-condensing trials; (2) Its amount was largely affected, as in the former series, by the range of temperature in the cylinder, but at the same time the density of the steam possessed great influence.

The application of mechanical ingenuity to the invention of

special machinery, whereby skilled labour has been superseded, and the continued reproduction of accurate copies of an original pattern have been assured, formed the main feature of a Paper on "The Manufacture of Small Arms" by Mr. John Rigby, Superintendent of the Royal Small Arms Factory, Enfield. The author touched briefly upon the history of the modern systems of manufacture, especially with reference to the production of the magazine-rifle at Enfield, and described some of the special machines used in that factory, with an account of its organization and functions. The only other occasion on which the subject of machine-made and interchangeable small-arms has been before the Institution was in November, 1851, when Colonel Samuel Colt, U.S.A.,¹ described the system adopted in the production of the rotating chambered-breech revolvers he contributed to the Great Exhibition of 1851.

The Paper by Mr. Walter Pitt dealing with "Plant for Harbour and Sea-Works" embraced details of three classes of machinery—(1) For making concrete; (2) For transferring it from the place of manufacture to the site of the work; and (3) For placing it in position.

The story of the voyage of the s.s. "Umbria" from Liverpool to New York in December, 1892, when a serious accident occurred to the propellor-shaft, was told in a brief communication entitled "The Break-down of the 'Umbria'" by Mr. T. Sopwith, who was one of the passengers and had permission to spend many hours in the engine-room when the repairs were being effected. A strong hoop was first bolted over the fracture and then three of the spare bolts used for connecting the different sections of the screw-shaft were employed to tie together the thrust collars on each side of the injured portion, and these were held in place by an outer hoop. A full-sized model of the shaft as repaired was exhibited.

To any maritime nation the operations connected with the raising of sunken vessels, with descriptions of the plant available for the purpose, cannot fail to possess interest. The Paper by Mr. C. J. More on "Wreck-Raising in the River Thames" was therefore received with pleasure; and it has been sought to make it a medium for obtaining other accounts of appliances for raising wrecks, especially in deep water, with particulars of the difficulties which present themselves and of the means adopted to overcome them.

¹ Minutes of Proceedings Inst. C.E., vol. xi. p. 3.

IN MINING AND METALLURGY some valuable contributions were received—notably, an account of the history and development of the Broken Hill Proprietary Company's Mine in New South Wales. In recent reports it was stated that from this single mine silver and lead to the value of over £8,250,000 sterling had been taken within seven years and that it continued to yield 220,000 ozs. of silver and between 600 and 800 tons of lead per week. The character and extent of the ore-bodies and the methods adopted in mining and in the extraction of the metals were described in the Paper on "Mining and Ore-Treatment at Broken Hill, N.S.W." by Mr. M. B. Jamieson and Mr. John Howell. The completeness of this communication may be gathered from the following summary of its contents:—1. Geology of the district and description of the ore. 2. Method adopted in mining and sustaining the ground. 3. Shafts, and hauling- and pumping-plant. 4. Ore-reduction works, including: (a) smelting-plant; (b) ore-dressing mill; (c) leaching-plant; (d) amalgamating mill; and (e) refinery plant. 5. General surface-works: (a) saw-mill; (b) railway; (c) electric light; (d) water-supply and rainfall. 6. Labour—its distribution, cost and efficiency. 7. Financial and general. The mining operations at Broken Hill are considered to be unique—alike in their nature and in the colossal scale on which they are conducted—and the communication contained much matter new to European mining engineers.

As the art of Smelting applied to the extraction of precious metals from their ores is being continually improved, an accurate record of the latest developments, with the various statistics relating thereto, could not be otherwise than interesting. In a Paper on "Smelting Processes for the Extraction of Silver and Gold from their Ores" by Mr. Henry F. Collins, an illustrated account was given of smelting- and calcining-furnaces of the most modern type in use on the American Continent. A second Paper dealt with "The Erection of Silver-Lead Smelting Works in Mexico" by Mr. James W. Malcolmson. This contained a description of a plant capable of treating 100 tons of ore daily, with provision for future extension. The works belong to the Michoacan Railway and Mining Company, and are situated at Las Trojes, Mexico, at an altitude of 9,000 feet above sea-level.

ELECTRICAL ENGINEERING has not been neglected. Five years have elapsed since there was a discussion at the Institution on Electrical Traction. In the interval considerable progress has been made, notably in the United States, in its application to tramways and railways. In a Paper by Dr. Edward Hopkinson

entitled "Electrical Railways: the City and South London Railway," a detailed description was given of the installation on the line in question. It was stated that the essential and novel feature in the locomotives was that the armatures of the motors were built directly upon the driving-wheel axles, while the magnets were supported partly on the axles and partly on the frames; thus, gearing of any description was obviated and the mechanism was reduced to its simplest form. Reference was also made to the recent progress in the United Kingdom in the application of electric traction to tramways, compared with similar work done on the Continent and in the United States.

In connection with this relatively modern branch of Civil Engineering the Paper on "Gas Power for Electric Lighting" by Mr. J. E. Dowson may be referred to. In this communication the Author advances reasons for believing that the Otto cycle is not the best for engines of large power and deals with the subject of the load-factor at several stations and with the most economical type of generating apparatus, urging that the present loss due to fuel, water and wages could be avoided if gas-power were employed instead of steam-power. To effect this he advocates the use of engines driven with generator-gas and also draws attention to the advantages, in certain cases, of using ordinary town-gas.

For several of the foregoing Papers Premiums have been awarded to Messrs. P. W. Willans, Edward Hopkinson, M. B. Jamieson, John Howell, John Rigby, G. E. W. Cruttwell and Walter Pitt, the details of which will be found in the Appendix.

OTHER SELECTED PAPERS.

Among the Papers accepted for printing alone in the Proceedings, it will be found that several relate to works carried out in India and in the Colonies.

Referring, in the first instance, to the improvement of Internal Communication, it may be stated that when it was decided to make a railway across the Kwaja Amran range, on the Afghanistani frontier of India, the selected route involved a tunnel estimated to take three years in construction. Pending the completion of the tunnel, it was determined to lay a temporary railway, rapidly and cheaply, over the mountains. The Paper on "The Khojak Rope Inclines" by Mr. W. J. Weightman described this part of the work and it is expected that the machinery and

plant employed in the execution of the tunnel will form the subject of another communication.

As a carefully prepared record of an extensive work, the "Description of the New 'A' Box and Signalling arrangements at the Waterloo Terminus of the London and South Western Railway," by Mr. Alfred W. Szlumper, will well repay study by those engaged in similar undertakings. This signal-station is probably one of the busiest in existence and the details given of many new adaptations—including the interlocking-apparatus and the electric block-and-lock instruments—cannot fail to attract attention. On the subject of Railway Signalling generally there is still much that demands thorough consideration.

The construction of "the River Piers of the Memphis Bridge," described by Mr. Geo. S. Morison, forms a valuable contribution to that portion of engineering literature which relates to the founding of massive structures in the beds of deep rivers. Dr. Du Riche Preller supplied an account of the "Zurich Water-Supply, Power and Electric Works."

Passing now to Sea-Coast works it is satisfactory to record the receipt of Papers dealing with the improvement of the Harbours of Otago and Westport, both in New Zealand. The former, by Mr. G. M. Barr, treats of the physical features and natural conditions of the entrance at various periods; while the latter, by Mr. J. A. Wilson, is an account of the application of training and concentrating piers to the bar of a tidal river. An analysis of the "Relative Powers of Lighthouse Lenses" was furnished by Mr. Alan Brebner, B.Sc.

Mr. Robert Gordon, in his Paper on "Hydraulic Work in the Irawadi Delta," furnishes a narrative of the way in which the delta of the river—one of the largest in the British Empire—has been protected from inundation. The Author restricted himself to a concise description of the embankments which were under his charge for many years and to a brief notice of their action upon the river floods and of the variation and changes brought about by the works on the condition of the river. This Paper will be found to possess a considerable amount of general as well as local interest, dealing, as it does, with the important problem of the reclamation of land, the prevention of floods and the improvement of rivers, upon which little information has yet appeared in the Proceedings.

In the group including the design, construction and adaptation of machinery and of mechanical appliances three Papers may be noted. One is on "A Method of Testing Engine-Governors"

by Mr. H. B. Ransom. In a terse introduction the Author urges the desirability of actual experimental results and of a definite system for testing governors, to check calculations and to obtain new facts, particularly as to "time" factors. The second, by Mr. Joseph Harrison, deals with "Radial Valve Gears" and is considered to contain much useful information; while the third, on "A New Method of Designing Wheel-Teeth" by Mr. A. Sharp possesses much practical interest.

Awards for some of the above have been adjudged to Messrs. Geo. S. Morison, Robert Gordon, Alan Brebner, B.Sc., H. B. Ransom, G. M. Barr, A. W. Szlumper, J. Harrison, Wh.Sc., E. G. Holtham, and C. S. Du Riche Preller, the particulars of which are given in an Appendix.

JAMES FORREST LECTURESHIP.

The origin of this lectureship was stated in the Report of the Council for 1891. It has since been decided that a lecture shall be delivered annually on the 4th of May, the anniversary of the election of the Secretary as an Associate of the Institution, which took place in 1852. Dr. William Anderson, F.R.S., Member of Council, consented to be the first lecturer, the subject being "The Interdependence of Abstract Science and Engineering." The Lecture, which was delivered on the 4th of May, was extremely well received and will be printed in the fourth volume of the Proceedings, to be issued during the current year. The absence of the Secretary on this occasion, due to ill-health, was much regretted.

STUDENTS' MEETINGS AND VISITS TO WORKS.

Neither as regards the merit of the Papers read nor the attendance of Students, can the Supplemental Meetings of the past Session be considered so successful as those of the Session 1891-92. Owing to a lack of Papers it was not possible to make arrangements for any Meetings before Christmas, and the average attendance at the nine Meetings held during the spring has been 32 only, as against 42 last year. Having regard to the fact that there are some 300 Students resident in and around London, the Council cannot but deplore that only 10 per cent. of that number have been present at the Meetings arranged solely for their benefit. Reference to the record of attendances shows that,

while a few regularly take advantage of these opportunities of obtaining knowledge, the majority of London Students are indifferent to them. These remarks apply also to Visits to Works, although perhaps not to the same extent, as many Students find difficulty in obtaining leave during the day. The Council would repeat the hope expressed on previous occasions that members will do all in their power to enable their pupils to join these inspections, which are at once interesting and instructive. Ten visits were made during the past Session, the average attendance being 23, the same as for the Session 1891-92.

The Council has had pleasure in awarding Miller Prizes in the case of five of the Papers read at the Supplemental Meetings, viz., to Messrs. C. D. Barker, D. Carnegie, J. W. Steven, F. G. Baily, B.A., and A. S. Butterworth, and it has been decided to print, either in whole or in part, in the Minutes of Proceedings the Papers by Messrs. Barker, Carnegie and Steven.

During the past Session the Council granted to Students belonging to the various local Associations the privilege of sending to the Institution, to be received in competition for Miller Prizes, Papers read at the provincial centres. The conditions are that Papers shall be sent in the first instance to the Institution to be reported upon. If approved, they are returned to the Authors to be read, after which they must again be sent to the Institution to be considered by the Premium Committee of Council. Five such Papers have been submitted during the past Session, two from Glasgow and three from Newcastle-on-Tyne. Awards have been made to Messrs. W. R. Copland, jun., and P. M. Pritchard for Papers read at the local associations of Glasgow and Newcastle-on-Tyne respectively.

The Special Visits to Works in May last year, arranged in order to afford an opportunity for Students in London and in the country to meet and become better acquainted, proved so successful that it was determined to organize a Second Series, to take place on the 10th, 11th, and 12th of May this year, on the last of which days the Students' Eighteenth Annual Dinner was held. The visits on the 10th of May were to the Head-quarters of the Metropolitan Fire Brigade and to the Houses of Parliament, to inspect the Clock Tower and the Ventilating and Lighting arrangements. On the following day the works of the Tottenham and Forest Gate Railway, from Forest Gate to Hoe Street, were inspected, Mr. Arthur C. Pain, M. Inst. C.E., kindly receiving the party at luncheon. The afternoon of that day was devoted to new works at the Blackwall entrance to the West India Dock,

the party returning by steamer to Charing Cross Pier. On the 12th of May Stations of the Westminster Electric Supply Corporation and the London Hydraulic Power Company, Lambeth Palace, and the Generating Station of the City and South London Railway Company at Stockwell were visited. The attendances were as follows:—First day, 29; second day, 65; third day, 71. Of these 23 came from various parts of the country, including local Associations at Manchester, Glasgow, Birmingham and Newcastle-on-Tyne, and 7 were students of the Royal Indian Engineering College at Coopers Hill.

The four local Associations above referred to have, under energetic honorary secretaries, maintained their reputation for good work. There can be no doubt that these bodies assist in promoting the welfare of the Institution, and the Council hopes that members in the provinces will do all in their power to aid these centres, by attending meetings, by affording opportunities of visits to works, and by encouraging their pupils to apply for admission as Students of the Institution and thus become eligible to share in the benefits of the local societies.

LIBRARY CATALOGUE.

It has been decided to adopt, for the entries in the new catalogue, the system now in vogue at the British Museum. This entails the abandonment of the more diffuse method previously followed, while at the same time the new catalogue will afford all the information which can reasonably be expected and will be considerably less costly to produce. As a preliminary to printing, the existing MS. slips are being critically revised on the following lines: 1. Nearly all the entries are being considerably abbreviated, enough being left to show the scope of each work. 2. Authors appearing under different forms of their names, and the headings selected for institutions and corporate bodies, will be identified and their works brought together, so as to ensure consistency. 3. Cross-references from translators and editors are being removed as a rule; those not removed will be re-written, as the form in which they previously stood was too much abbreviated to be of use. 4. Dates (approximate) are being assigned to undated works. 5. Entries in foreign languages will be checked. 6. Works which partake of the nature of advertisements or trade catalogues will be excluded.

ENGINEERING CONGRESS AT CHICAGO.

Application having been made to the Council to nominate one or more of its members to represent the Institution at the Engineering Congress proposed to be held in July and August next in connection with the Chicago Exhibition, it is announced with much satisfaction that Sir Benjamin Baker, Vice-President, has, provisionally, consented to fill the office in question.

SANITARY INSTITUTE.

A Petition having been presented to the Queen in Council, praying for the grant of a Royal Charter of Incorporation to the Sanitary Institute, the Council considered it a duty to oppose the petition, for reasons fully set forth in the case in opposition thereto on behalf of the Institution of Civil Engineers, in reference to which Sir Frederick Bramwell, Bart., Past-President, was asked to confer with Counsel.

Mr. J. Fletcher Moulton, Q.C., and Mr. Francis R. Y. Radcliffe, appeared before the Privy Council for the Institution. In the result the Petition of the Sanitary Institute has not been acceded to.

THE PREMISES.

Consideration of the question of rebuilding the premises on the present site has been necessarily postponed until the powers obtained in 1887 and revived by the Westminster (Parliament Street, &c.) Improvements Act, 1892, shall have been exercised by the undertakers of that Act, or shall have lapsed. At present the Council is informed that the exercise of those powers is, in the discretion of the Board of Trade, contingent upon the completion of certain negotiations between the undertakers and other bodies. The term during which the necessary authority of the Board of Trade may be obtained by the undertakers will expire in December, 1893.

The Council desires to state that as the rents derived from No. 26 Great George Street have diminished by over £400

per annum, and as, owing to the extensive repairs necessary, no interest is being obtained on the capital invested in the purchase of the lease of No. 27 Great George Street, it is extremely desirable, from a financial point of view, apart from other urgent considerations, that the question of rebuilding, which has been so long under consideration, should be definitely settled as early as possible.

ABSTRACT of RECEIPTS and EXPENDITURE

RECEIPTS.

<i>Dr.</i>	£.	s.	d.	£.	s.	d.
To Balance, April 1st, 1892, viz. :—						
On Deposit	7,000	0	0			
Cash in the hands of Treasurer.	1,215	4	10			
" " Secretary.		9	11	10		
					8,224	16 8

INCOME.

— Subscriptions :—	£.	s.	d.			
Arrears	596	9	0			
Current	15,243	1	0			
Advance	722	19	6			
				16,562	9	6
— Library Fund				155	5	0
— Minutes of Proceedings :—Re- payment for Binding, &c.				402	17	0
— Dividends : 1 year on						

£		Institution Dividends.
6,000	2½% Consols	160 12 0
6,000	Metropolitan Board of Works 3½% Stock	204 15 0
6,000	Great Eastern Railway 4% Debenture Stock	234 0 0
8,000	Great Northern Ry. 3% Debenture Stock	234 0 0
6,000	Great Western Ry. 4% Debenture Stock	234 0 0
3,000	Lancs. and Yorks. Ditto	117 0 0
8,000	London & N. W. Ditto	312 0 0
6,000	London & S.W. 3% Ditto	175 10 0
6,000	Midland Ry. 3% Ditto	175 10 0
4,000	North Eastern 4% Ditto	156 0 0

NEW PURCHASES.

3,000	Lancs. & Yorks. Railway 4% Debenture Stock (6 Months Dividend)	58 10 0
4,000	London & South W. Ry. 3% Debenture Stock	0 0 0
		2,061 17 0

£86,000 Total nominal or par value.

Whitworth Legacy.

£1,400	5% Debenture Stock in Sir Joseph Whitworth & Co., Ltd.	68 5 0
4,000	Four hundred £10 shares in Ditto	400 0 0
		468 5 0

£5,400 Total nominal or par value.

— Rents—No. 26 Great George St.	225	0	0			
No. 27 Great George St.	926	6	0			
— Interest on Deposit	52	9	0			
				1,203	15	0
					20,854	8 6

Carried forward £29,079 5 2

from the 1st APRIL, 1892, to the 31st MARCH, 1893.

EXPENDITURE.

Cr.	GENERAL EXPENDITURE.	£.	s.	d.	£.	s.	d.	£.	s.	d.
By House and Establishment Charges:—										
Repairs:—	Nos. 24 & 25 Great George Street	402	15	11						
	No. 26 Gt. George St.		9	11	6					
	No. 27 Gt. George St.	232	18	10						
					645	6	3			
	Rent of No. 27 Great George Street				585	0	0			
	Rates and Taxes:—									
	Nos. 24 & 25 Great George Street	608	16	10						
	No. 26 Gt. George St.	159	5	1						
	No. 27 Gt. George St.	168	8	10						
					936	10	9			
	Insurance:—Nos. 24 & 25 Great George Street	46	19	6						
	No. 26 Gt. George St.	5	1	3						
	No. 27 Gt. George St.	6	2	0						
					58	2	9			
	Rent of Telephone				22	2	0			
	Fixtures and Furniture				145	9	4			
	Lighting and Warming:—									
	Nos. 24 & 25 Great George Street	178	9	4						
	No. 26 Gt. George St.	16	14	7						
	No. 27 Gt. George St.	9	16	3						
					205	0	2			
	Refreshments at Meetings				61	2	9			
	Assistance at Meetings				35	5	0			
	Monthly Receptions				105	2	2			
	Students' Meetings and Visits				92	19	6			
	Household Expenses				206	11	8			
								3,098	12	4
—	Postages, Telegrams, and Parcels				233	2	10			
—	Stationery and Printing				702	2	4			
—	George Stephenson Medal				2	7	6			
—	Diplomas				38	11	0			
—	Annual Dinner (balance of 1892 and part 1893)				348	4	4			
								1,324	8	0
—	Salaries				2,700	0	0			
—	Clerks, Messengers, and Housekeeper				834	13	6			
—	Retiring Allowance to late Librarian				200	0	0			
—	Donations to late Housekeeper and Messenger				82	0	0			
								3,816	13	6
—	Library:—Books				223	19	3			
	Periodicals				53	19	2			
	Binding				46	10	2			
								324	8	7
—	Publications:—									
	“Minutes of Proceedings,” Vols. cviii., cix., cx. and cxi.				7,595	11	8			
	Charter, By-Laws, and Lists of Members				140	0	5			
								7,735	12	1
	Carried forward							£16,299	14	6

ABSTRACT of RECEIPTS and EXPENDITURE

<i>Dr.</i>	RECEIPTS— <i>continued.</i>			
			£.	s. d.
	Brought forward		29,079	5 2

CAPITAL.				
To Admission-Fees		3,667	13	0
— Life-Compositions		312	7	6
		3,980	0	6

Carried forward . . £33,059 5 8

from the 1st APRIL, 1892, to the 31st MARCH, 1893.

EXPENDITURE—continued.

Cr.		£.	s.	d.
	Brought forward.	16,299	14	6
By Disbursements <i>re</i> Appeal against Charter to Sanitary Institute	}	6	16	8
— Legal Expenses:—				
Westminster (Parliament Street) Improvements Bill	}	72	17	10
General		5	18	4
Tufton Street Stables		23	7	10
No. 26 Great George Street		21	8	2
" 27 " " (per chase of Lease, &c.)	}	97	14	2
		221	6	4
		228	3	0
		16,527	17	6

CAPITAL.

By Purchase of				
£3,000 Lincs. & Yorks. Ry. 4 % } Debenture Stock		4,090	15	6
£4,000 L. & S. W. Ry. 3 % } Debenture Stock		4,161	10	0
		8,252	5	6
£7,000 Total nominal or par value.				
— Fees <i>re</i> Forged Transfers Act		2	6	8
		8,254	12	2

Carried forward . . £24,782 9 8

ABSTRACT of RECEIPTS and EXPENDITURE

RECEIPTS—continued.

Dr.				£.	s.	d.
	Brought forward			33,059	5	8
	TRUST-FUNDS.					
	<i>Telford Fund.</i>			£.	s.	d.
To Balance of Telford Premium			13 14 6			
„ Dividends:—1 year on						
£.	s.	d.				
5,439	11	0	2½% Consols	146	16	0
3,299	2	0	Ditto (Unexpended)	88	4	0
			Dividends)			
				248	14	6
£8,738	13	0				
	<i>Manby Donation.</i>					
£250	0	0	Great Eastern Ry. 4% Debenture Stock	9	15	0
	<i>Miller Fund.</i>					
3,125	0	0	2½% Consols	83	9	8
2,004	17	5	Ditto (Unexpended)	53	12	0
			Dividends)			
				137	1	8
£5,129	17	5				
	<i>Howard Bequest.</i>					
£551	14	6	2½% Consols	14	18	4
	<i>Trevithick Memorial.</i>					
£103	0	0	2½% Consols	2	14	8
	<i>Crampton Bequest.</i>					
£512	15	11	2½% Consols	13	14	0
	<i>James Forrest Lectureship.</i>					
£320	0	0	South Eastern Ry. 5% Debenture Stock	15	12	0
				442	10	2
				£33,501	15	10

SUMMARY OF INVESTMENTS.

	£.	s.	d.
INSTITUTION INVESTMENTS	66,000	0	0
FREEHOLDS OF NOS. 24, 25 & 26 GT. GEORGE ST.	40,000	0	0
WHITWORTH LEGACY:—400 SHARES OF £10, AND £1,400 5% DEBENTURE STOCK IN THE FIRM OF SIR JOSEPH WHITWORTH AND Co., Ltd.	5,400	0	0
TRUST-FUNDS INVESTMENTS:—			
Telford Fund	8,738	13	0
Manby Donation	250	0	0
Miller Fund	5,129	17	5
Howard Bequest	551	14	6
Trevithick Memorial	103	0	0
Crampton Bequest	512	15	11
James Forrest Lectureship	320	0	0
	15,606	0	10
	£127,006	0	10

from the 1st APRIL, 1892, to the 31st MARCH, 1893.

EXPENDITURE—continued.

[illegible]

Examined with the Books and found correct.

(Signed)

F. S. COURTNEY } *Auditors.*
S. HANNA }

JAMES FORREST, Secretary.

4th May, 1893.

[THE INST. C.E. VOL. CXIV.]

PREMIUMS AWARDED.

SESSION 1892-93.

The following is a detailed list of the Awards made for Original Communications submitted during the past Session :—

FOR PAPERS READ AND DISCUSSED AT THE ORDINARY MEETINGS.

1. A Telford Medal and a Telford Premium to Peter William Willans,¹ M. Inst. C.E. (deceased), for his Paper on "Steam-Engine Trials."
2. A George Stephenson Medal and a Telford Premium to Edward Hopkinson,² M.A., D.Sc., M. Inst. C.E., for his Paper on "Electrical Railways: the City and South London Railway."
3. Telford Medals and Telford Premiums to Mathew Buchan Jamieson, Assoc. M. Inst. C.E., and John Howell, for their joint Paper entitled "Mining and Ore-Treatment at Broken Hill, New South Wales."
4. A Watt Medal and a Telford Premium to John Rigby, M.A., for his Paper on "The Manufacture of Small Arms."
5. A Telford Premium to George Edward Wilson Cruttwell, M. Inst. C.E., for his Paper on "The Foundations of the two River Piers of the Tower Bridge."
6. A Telford Premium to Walter Pitt, M. Inst. C.E., for his Paper on "Plant for Harbour- and Sea-Works."

FOR PAPERS PRINTED IN THE PROCEEDINGS WITHOUT BEING DISCUSSED.

1. A Telford Medal and a Telford Premium to George Shattuck Morison, M. Inst. C.E., for his account of "The River Piers of the Memphis Bridge."
2. A Telford Medal and a Telford Premium to Robert Gordon, M. Inst. C.E., for his Paper entitled "Hydraulic Work in the Irawadi Delta."
3. A Telford Medal and a Telford Premium to Alan Brebner,³ B.Sc., Assoc. M. Inst. C.E., for his Paper on "Relative Powers of Lighthouse Lenses."

¹ Has previously received a Watt Medal and a Telford Premium.

² Has previously received a Telford Medal and a Telford Premium.

³ Has previously received a Miller Scholarship.

4. A Watt Medal and a Telford Premium to Herbert Byrom Ransom,¹ Assoc. M. Inst. C.E., for his Paper on "A Method of Testing Engine-Governors."
5. A Telford Premium to George Morrison Barr, M. Inst. C.E., for his account of the "Improvement of the Entrance of Otago Harbour, New Zealand."
6. A Telford Premium to Alfred Weeks Szlumper,² M. Inst. C.E., for his Paper on "The Signalling at the Waterloo Terminus of the London and South-Western Railway."
7. A Telford Premium to Joseph Harrison, Wh. Sc., Assoc. M. Inst. C.E., for his Paper on "Radial Valve-Gears—Analysis of the Motion of the Valve."
8. A Telford Premium to Edmund Gregory Holtham, M. Inst. C.E., for his description of the "Chinipas Aqueduct and Mineral Railway, North-West Mexico."
9. A Telford Premium to Charles Sheibner Du Riche Preller,³ M.A., Ph.D., Assoc. M. Inst. C.E., for his account of the "Zurich Water-Supply, Power and Electric Works."

FOR PAPERS READ AT THE SUPPLEMENTAL MEETING OF STUDENTS.

1. A Miller Prize to Charles Davidson Barker, Stud. Inst. C.E., for his account of the "Methods adopted in Constructing the Glasgow Central Railway—Bridgeton and Trongate Contracts."
2. A Miller Prize to David Carnegie,⁴ Stud. Inst. C.E., for his Paper on "The Manufacture and Efficiency of Armour-Plates."
3. A Miller Prize to John Wilson Steven, Stud. Inst. C.E., for his Paper on "The Introduction of Rubble Blocks into Concrete Structures."
4. A Miller Prize to Francis Gibson Baily, B.A., Stud. Inst. C.E., for his Paper entitled "Some Points in the Regulation of Direct-Current Motors."
5. A Miller Prize to Arthur Shaw Butterworth, Stud. Inst. C.E., for his Paper on "The Disposal of Town-Refuse by Burning and the Application of the Heat thereby Generated."

¹ Has previously received a Miller Scholarship.

² Has previously received a Telford Medal and a Telford Premium.

³ Has previously received Telford Premiums.

⁴ Has previously received a Miller Prize.

FOR PAPERS READ AT LOCAL ASSOCIATIONS OF STUDENTS.

1. A Miller Prize to William Robertson Copland, Jun., Stud. Inst. C.E. (of Glasgow), for his account of "The Tarapaca Waterworks."
2. A Miller Prize to Philip Morris Pritchard, Stud. Inst. C.E. (of Newcastle-on-Tyne), for his Paper on "The Relative Water and Fuel Consumption of English and American Locomotives."

* * It has been determined to print the first three Students' Papers, either in whole or in part, in the Minutes of Proceedings.

SUBJECTS FOR PAPERS.

SESSION 1893-94.

THE COUNCIL of the Institution of Civil Engineers invites Original Communications on the Subjects included in the following List, as well as on any other questions of professional interest. This list is to be taken merely as suggestive, and not in any sense as exhaustive. For approved Papers the Council has the power to award Premiums, arising out of Special Funds bequeathed for the purpose, the particulars of which are as under:—

1. The TELFORD FUND, left "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) produces £235 annually.

2. The MANBY DONATION, of the value of about £10 a year, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings."

3. The MILLER FUND, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) realises £140 per annum. Out of this Fund the Council has established a Scholarship,—called "The Miller Scholarship of The Institution of Civil Engineers,"—and is prepared to award one such Scholarship, not exceeding £40 in value, each year, and tenable for three years. No Paper will be received from a Student in competition for the Miller Scholarship and the Miller Prizes when he has become qualified by age, viz. twenty-five years, for election into the Corporation.

4. The HOWARD BEQUEST, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the Uses or Properties of Iron or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to nearly

£15. It has been arranged to award this prize every five years, commencing from 1877. The next award will therefore be made in 1897.

5. The CRAMPTON BEQUEST of £500, free of legacy duty, has been invested in the purchase of £512 15s. 11d. 2½ per cent. consols, and the income arising therefrom is now £13 15s. This trust is for the purpose of founding "a Prize to be called the 'Crampton Prize,' so that the interest of the said legacy shall be annually expended in a medal or books or otherwise . . . for presentation to the Author of the best Paper on 'The Construction, Ventilation and Working of Tunnels of Considerable Length,' or, failing that then on any other subject that may be selected."

6. The balance of the TREVITHICK MEMORIAL FUND, amounting to £100 0s. 9d., has been accepted for a periodical Premium to be called after Richard Trevithick. This sum has been placed in £103 2½ per cent. consols, upon which the interest is £2 15s. a year.

The Council will not make any award unless a communication of adequate merit is received, but will give more than one Premium if there are several deserving memoirs on the same subject. In the adjudication of the premiums no distinction will be made between essays received from members of the Institution or strangers, whether Natives or Foreigners, except in the cases of the Miller and the Howard bequests, which are limited by the donors.

LIST.

1. Description of any new types of Mountain Railways, with the design and construction of Locomotives for the same.
2. The Laying of Steel Railway Sleepers in the road, and their subsequent behaviour.
3. The Design and Construction of Railway Passenger-Carriages, having reference to (a) strength and safety; (b) ease and smoothness of motion; (c) durability; (d) moderate dead-weight; (e) facility for entrance and exit; (f) lavatory accommodation; (g) provision for refreshments; and (h) sleeping arrangements.
4. The Cost of Working Electrical Tramways, taking account of interest on capital, and of a sinking fund for depreciation.
5. Methods for the Prevention of the Waste of Water and for the detection of the same.

6. The Removal of Obstructions in Water-Mains.
7. The Failures of Reservoir-Embankments and Dams, and the Causes to which they may be ascribed, with suggestions for avoiding or remedying them.
8. Experiments on the Purification of Sewage, by Filtration and otherwise.
9. The Disposal of Town Refuse by Burning and the application of the heat thereby generated.
10. The Working of Inclined Retorts in Gasworks.
11. The Design and Construction of Modern Gas-holders of large size.
12. The Carburetting of Gases for Illuminating-purposes.
13. The most suitable form of Electric-Light Mains, having regard to durability, economy of conducting-material and facility for making and laying house-connections.
14. The Risks of Electric Lighting to life and property, with the means to be taken to prevent or to reduce them.
15. Rock-boring and Drilling Machinery for Tunnelling and other purposes.
16. The various Systems of Mechanical Ventilation for Mines, Long Tunnels, Underground Railways, Sewers, &c.
17. The Laying-out of Engineering Workshops.
18. Modern Machine-Tools and Workshop Appliances.
19. The Manufacture of Casks and Barrels by Machinery.
20. Experiments on the Condensation of Steam.
21. The Continuous-Running of Steam-Engines, and other Motors.
22. The best Arrangement of Engine for any given Electric-Light Station.
23. The various Systems of utilizing Compressed Air, Water and Liquefied Gases for Motive-power.
24. The recent developments of Mechanical Refrigeration.
25. Coal-shipping Appliances and Discharging-apparatus.
26. The Method of Trans-shipping Grain, and its classification and storage in Granaries.
27. Modern Ship-building Machinery.
28. The most recent types of (a) Passenger- and Mail-Steamers; (b) Cargo-Steamers; (c) War-Ships, and (d) Ferry-Steamers.
29. The Comparative Efficiency of different Types of Marine Engines.
30. Electrical Motors for (a) Inland Navigation; (b) Ocean Vessels.
31. Mechanical Propulsion for Life-boats and for small undecked vessels.

32. Coal-winning in seams situated at great depths below the surface.
33. The Surface-arrangements of Collieries; including those for banking, cleaning, sorting, screening, and shipping the Coal.
34. Coal-washing and Briquette-making Plant.
35. Recent Improvements in Pumping-Machinery.
36. Electric Lighting and Haulage-Plant in Mines and Collieries.
37. Blast-Furnaces *versus* Reverberatories.
38. The Modern Practice in the Manufacture of Finished Steel, having regard to increase of output and diminution of cost.
39. Processes for the Extraction of Aluminium from its ores.
40. Extraction of Gold and Silver from their ores by wet methods, including chlorination and treatment by cyanide solution, the Russell process, &c., and a description of the Plant employed.
41. On the Concentration of Ores by wet and dry methods.
42. The Effect of small quantities of Impurities in Commercial Copper as regards its use in Electrical work.
43. The Electro-deposition of Copper.
44. On the application of Water-Power and its Transmission to a distance by Electricity.
45. The Design of Electric Locomotives.
46. The Practical Working of Multiphase Alternate-Current Motors.
47. The Forms of Electrical Conductors for lighting, stationary power, heating and traction purposes.
48. The transport of Petroleum in Bulk, and the Prevention of Risks from fire and explosions.
49. The Manufacture of Modern Fixed Ammunition.

INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

In writing these Essays the use of the first person should be avoided. They should be legibly transcribed on foolscap paper, on one side only, leaving a margin on the left side, in order that the sheets may be bound. Every Paper must be prefaced by an Abstract of its contents not exceeding 1,500 words in length.

Illustrations, when necessary, should be drawn on tracing-paper, to as small a scale as is consistent with distinctness, but in no case should any Fig. exceed $6\frac{1}{2}$ inches in height. When an illustrated communication is accepted for reading, a series of

Diagrams will be required sufficiently large and boldly drawn to be clearly visible at a distance of 60 feet. These diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published, will not be accepted by this Institution.

The Communications must be forwarded to the Secretary of the Institution, from whom any further information may be obtained. There is no specified date for the delivery of MSS., as when a Paper is not in time for one session it may be dealt with in the succeeding one.

WILLIAM POLE, *Honorary Secretary*,
JAMES FORREST, *Secretary*.

THE INSTITUTION OF CIVIL ENGINEERS,
25, Great George Street, Westminster, S.W.
August, 1893.

EXCERPT BY-LAWS, SECTION XV., CLAUSE 3.

“Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. Except as hereinbefore provided, no person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council.”

NOTICE.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had premiums awarded to them, the Authors have advanced somewhat doubtful theories, or have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat that the Institution as a body must not be considered responsible either for the statements made, or

for the opinions expressed in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the inquiry; but that such notice, or award, must not be regarded as an expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS.

RECEIVED BETWEEN APRIL 1, 1892, AND MARCH 31, 1893.

AUTHORS.

- Anderson, A. M. No. 2,681.—Some Notes on Economy in Railway Construction, with special reference to the Construction of the Calañás and Tharsis Railway. With an Abstract and 5 Drawings.
- Apjohn, J. H. No. 2,669.—The Design, and the Difficulties Experienced in the Construction of the Walls of the Kidderpore Docks. With Appendix, 3 Plates and 8 Figs.
- Ashcroft, A. G. No. 2,690.—Malleable Cast-Iron. With 8 Tables and 8 Figs.
- Ashton, H. T. No. 2,701.—On the Manufacture of Modern Fixed Ammunition. With an Abstract, Appendix and 1 Sheet of Tracings.
- Barr, G. M. No. 2,632.—Improvement of the Entrance to Otago Harbour, New Zealand. (Vol. cx., p. 304.)
- Blomfield, H. A. No. 2,643.—The North Shore Water-Supply, New South Wales. With 4 Drawings and 6 Photographs.
- Brebner, A. No. 2,660.—Relative Powers of Lighthouse Lenses. With 2 Drawings. (Vol. cxi., p. 296.)
- Brown, A. No. 2,654.—The most recent Types of Ferry Steamers. With an Abstract and 2 Drawings.
- Burton, Prof. W. K. No. 2,650.—Regulating the Rate of Filtration through Sand. With a Drawing. (Vol. cxii., p. 321.)
- Caccia, J. E. No. 2,645.—Faenza-Florence Railway. With 8 Drawings and 20 Photographs.
- . No. 2,695.—S. Ellero-Saltino (Vallombrosa) Rack Railway. With an Abstract, 12 Drawings and 6 Photographs.
- Collins, E. No. 2,688.—Methods for the Prevention of Waste of Water and for the Detection of the same. With 8 Plans and 7 Small Diagrams.

AUTHORS.

- Collins, H. F. No. 2,655.—On Smelting Processes for the Extraction of Silver and Gold from their Ores. With an Abstract, 6 Tables, and 5 Tracings. (Vol. cxii., p. 112.)
- Colson, C., and Colson, C. H. No. 2,631.—The 160-ton Hydraulic Crane at the Malta Dockyard Extension Works. With 1 Tracing and 3 Photographs. (Vol. cxiv. p. 284.)
- . No. 2,653.—Malta Dockyard Extension Works.—Removal of Rock in Entrance-Channel of Hamilton Dock. With 2 Tracings and 4 Photographs.
- Commans, R. E. No. 2,708.—Concentration and Sizing of Crushed Ore and other Minerals. With 15 Blue Prints.
- Cruttwell, G. E. W. No. 2,652.—The Foundations of the Two River Piers of the Tower Bridge. (Vol. cxiii., p. 117.)
- Darby, J. H. No. 2,637.—On Darby's Process for the Direct Carburization of Iron or Steel.
- Donkin, B., Jun. No. 2,635.—Measurement of the Velocity of Air in Pipes. With a Summary of Experiments. (Vol. cxii., p. 345.)
- . No. 2,698.—Experiments on the Condensation of Steam, with Iron and Other Cylinders. With 7 Tables and 14 Drawings.
- Dowson, J. E. No. 2,662.—Gas-power for Electric Lighting. With a Table, 11 Appendixes, and 3 Drawings. (Vol. cxii., p. 2.)
- Gibbons, T. H. No. 2,659.—Alteration of Gauge in the Plymouth Division of the Great Western Railway.
- Gordon, R. No. 2,678.—Hydraulic Work on the Irawadi Delta. With 4 Appendixes and 7 Sheets of Drawings. (Vol. cxiii., p. 276.)
- Griffiths, J. A. No. 2,672.—Windmills for Domestic and Pastoral Water-Supply. With Appendix and Abstract.
- Guttman, O. No. 2,711.—The Removal of the 'Iron Gates' of the River Danube. With 8 Sheets of Drawings.
- Harrison, J. No. 2,712.—Radial Valve-gears. Analysis of the Motion of the Valve. With an Abstract and 22 Figs. (Vol. cxiii., p. 170.)
- Haswell, C. H. No. 2,682.—Dissertation on Existing Formulas for Pile-Driving—their construction and factors of safety. With a formula.
- Henderson, H. No. 2,671.—The Removal of Corrosion and Obstructions in Water-Mains. With 8 Drawings.

AUTHORS.

- Holtham, E. G. No. 2,673.—The Chinipas Aqueduct and Mineral Railway, North-West Mexico. With an Abstract and 6 Tracings. (Vol. cxiii., p. 261.)
- Hopkinson, E. No. 2,666.—Electrical Railways—the City and South London Railway. With 6 Drawings. (Vol. cxii., p. 209.)
- Hunter, G. M. No. 2,664.—The Anglo-Chilian Nitrate Railway, Tocopilla, Chilé. With a Map and 3 Drawings.
- Jenkin, C. F. No. 2,633.—The Electric Lighting of Danger Buildings. With 7 Drawings. (Vol. cx., p. 367.)
- Jobson, C. No. 2,642.—Beetaloo Water-Works, South Australia. With an Abstract, 17 Appendixes, 32 Drawings, and 6 Photographs. (Vol. cxiii., p. 151.)
- Longridge, J. A. No. 2,628.—On the Use of Liners in Ordnance. (Vol. cix., p. 288.)
- Lüders, F. W. W. No. 2,657.—Petroleum Dock, with Tanks, Copenhagen. With 3 Blue Prints, 3 Tracings, and 2 Copies of Regulations.
- McDonald, J. No. 2,689.—Note on a Pneumatic Balanced Slide-valve. With 1 Drawing.
- Macgeorge, L. D. No. 2,699.—The Reconstruction of Cromwell Bridge, Otago, New Zealand. With 9 Photographs.
- Mackinnon, A. K. No. 2,703.—Notes on Oil- and Coal-Gases and Carburettors. With an Appendix, 12 Tables, and 5 Figs.
- MacLean, L. F. No. 2,694.—The Chenab Weir. With 2 Appendixes, an Abstract, 11 Drawings, and 6 Photographs. (Vol. cxiii., p. 314.)
- More, C. J. No. 2,691.—Wreck-raising in the River Thames. With 1 Tracing. (Vol. cxiv., p. 182.)
- Morison, G. S. No. 2,647.—The River Piers of the Memphis Bridge. With 14 Drawings and numerous Photographs. (Vol. cxiv., p. 289.)
- Palmer, P. H. No. 2,677.—Observations on the Use of Salt Water for Street Watering, &c.
- Perram, G. J. No. 2,700.—Note on the Flow off a Catchment-Area, near Mercara, South India. With a Table and 1 Drawing. (Vol. cxiii., p. 319.)
- Pitt, W. No. 2,693.—Plant for Harbour- and Sea-Works. With 9 Sheets of Drawings. (Vol. cxiii., p. 2.)
- Purcell, G. No. 2,640.—“The Use of Asphalt in Irrigation Works in California, U.S.A. (Vol. cx., p. 286.)

AUTHORS.

- Purdon, H. A. No. 2,668.—Some Statistics of the operating expenses of Narrow-gauge Secondary Railways in the United States of America. With an Abstract.
- Ransom, H. B. No. 2,702.—A Method of Testing Engine-Governors. With 13 Tracings and 2 Photographs. (Vol. cxiii., p. 194.)
- Redman, J. F. No. 2,658.—Dry-Dock Equipment and Ship-Repairs. With an Abstract, 1 Sheet of Tracings, 1 Blue Print, and 9 Photographs.
- Rigby, J. No. 2,629.—The Manufacture of Small Arms. With 10 Drawings. (Vol. cxi., p. 129.)
- Roberts, J. No. 2,679.—Mining-Operations. With 10 Drawings. (Vol. cxii., p. 326.)
- Roberts-Austen, Prof. W. C. No. 2,630.—On the Measurement of High Temperatures. With 7 Drawings. (Vol. cx., p. 152.)
- Robinson, J. No. 2,714.—Barry Graving-Docks. With 1 Drawing.
- Sadasewjee, J. No. 2,684.—The Baroda Water-Works. With 10 Appendixes and 17 Sheets of Illustrations.
- Sharp, A. No. 2,674.—A New Method of Designing Wheel-Teeth. With 21 Drawings. (Vol. cxiii., p. 241.)
- Smith, C. W., and Cobb, F. E. T. No. 2,670.—Irrigation in Victoria. With an Abstract, 2 Maps, and 1 Sheet of Drawings.
- Smith, W. A. No. 2,707.—On the Use of Australian Hard Woods for Street Paving.
- Sopwith, T. No. 2,709.—The Break-down of the R.M.S. "Umbria." (Vol. cxiii. p. 82.)
- Swarbrick, J. No. 2,663.—Withington Main Sewerage and Sewage-Disposal Works. With an Abstract and 1 Drawing.
- Szlumper, A. W. No. 2,648.—The Signalling at the Waterloo Terminus of the London and South-Western Railway. (Vol. cxi., p. 231.)
- Tait, W. A. P. No. 2,706.—Gaps in Station Lines. With 1 Drawing.
- Thompson, H. J. No. 2,676.—New Papaghni Bridge on the Madras Railway. With 5 Drawings.
- Trewhella, C. R. No. 2,646.—Circum-Etna Railway. With 59 Drawings, Specification, and description of vehicles.
- Tweddell, R. H. No. 2,710.—The Application of Hydraulic Pressure to the production of large Forgings. With 8 Drawings.

AUTHORS,

- Wetherly, J. H. No. 2,697.—Notes as to Connections of the Electric Light at the Mouth of Cadiz Harbour.
- Wicksteed, J. H. No. 2,641.—On a New Type of Testing-Machine. With 9 Drawings.
- Wilson, J. A., Jun. No. 2,638.—Westport Harbour Works, N.Z. With 4 Appendixes, 6 Plates, and an Abstract. (Vol. cxii., p. 301.)
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LIST OF DONORS TO THE LIBRARY.

FROM APRIL 1, 1892, TO MARCH 31, 1893.

A.

- | | |
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"Bulletin du Canal de Suez."
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 "Contract Journal, The."
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 "Deutsche Bauzeitung."
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 "Electrical Engineer, The."
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 "Électricien, L'. Revue inter-
 nationale de l'Électricité et des
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 "Engineering Magazine, The."
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 Mitchell Library, Glasgow, The.
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 "Moniteur Industriel, Le."
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"Monthly Weather Review, U.S.A."
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 "Revista de Engenharia."
 "Revista de Obras Publicas,"
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 "Revista de Obras Públicas,"
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 "Revue générale des Chemins
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 "Travelers' Official Guide of the Railway and Steam Navigation Lines in the United States and Canada."
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CHARLES HAWESLEY,		WILLIAM SHELFORD,
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*** *This Council will continue till May 1894.*

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JAMES FORREST.

EXTRA MEETING.

4 May, 1893.

HARRISON HAYTER, President,
in the Chair.

THE "JAMES FORREST" LECTURE.

Mr. HARRISON HAYTER, President, said the members were assembled on that occasion pursuant to the following notice, dated April 29th:—

"The Council beg leave to intimate that there will be an Extra Meeting on Thursday, May 4th, at 8 p.m., when Dr. W. Anderson, F.R.S., M. Inst. C.E., will deliver the first 'James Forrest' Lecture, his subject being 'The Interdependence of Abstract Science and Engineering.'"

The date chosen for these lectures was the anniversary of the election of the Secretary, Mr. Forrest, as an Associate of the Institution, which event took place on the 4th of May, 1852. They all regretted very much that Mr. Forrest was prevented by illness from being present on this occasion, but he had written a letter, which, he thought, the members would like to hear—

HASTINGS, *May 1st*, 1893.

MY DEAR SIR,—I deeply regret to have to report that my medical adviser will not sanction my return to London in time to be present at the lecture on Thursday evening. He considers that I am in too debilitated a condition to bear the strain of such an ordeal.

Under these circumstances I must ask you to express to the Council and members how highly the great compliment is appreciated, by which it is intended to identify my name, for all time, with the work of the Institution which I have, for many years, endeavoured faithfully and honestly to serve to the best of my ability.—With every respect, I remain, my dear Sir, yours very faithfully,

(Signed) JAMES FORREST, *Secretary*.HARRISON HAYTER, Esq., *President of The Inst. C.E.*

It was quite unnecessary to introduce Dr. Anderson to the meeting, and he would therefore, without further preface, call upon him to deliver the lecture.

“The Interdependence of Abstract Science and Engineering.”

By WILLIAM ANDERSON, D.C.L., F.R.S., M. Inst. C.E.

Before commencing the task which has been imposed upon me by the Council, I think it will be well to explain the origin of the “James Forrest Lectureship.”

During the Session of 1889–90 the Council of the Institution determined to have a portrait of Mr. Forrest painted with the view of presenting it to the Institution. An admirable likeness was produced by Mr. Wm. M. Palin, and it was presented at the Ordinary Meeting of November 11, 1890. As soon as the members had seen the portrait a large number expressed a wish to have an engraving of it; a Committee was formed outside the Council, funds were rapidly collected, and an excellent engraving, by Mr. Thomas Faed, R.A., was produced and distributed, while the surplus fund, amounting to about £500, was placed at the disposal of the Secretary, who determined that it should be devoted to the establishment of a “James Forrest” Lectureship, and that it should be administered by the governing body of the Institution for the time being, who would select the lecturer and determine the subject of his discourse.

This is the first lecture under the trust. The high and undeserved honour of delivering it was imposed on me; I accepted the task with much hesitation and misgiving, being deeply conscious that I was incompetent to do justice to the occasion.

The theme which has been prescribed is “The Interdependence of Abstract Science and Engineering,” and I imagine that the subject has been chosen because of an uneasy feeling, which possesses many thoughtful men, that this country is not keeping pace with its neighbours in engineering progress, and that we shall, in the future, have to pay more attention to abstract science and its application to practice, than we have been, so far, in the habit of doing, if we are to come out victorious from the competition, ever increasing in keenness, which we meet with from abroad, and which our system of unrestricted trade tends so much to foster. It is impossible to visit the Continent of Europe, the United States of America or even our

own Colonies, without feeling conscious that, in many respects, their engineering works and their factories, to say nothing of their military and naval arsenals, exhibit the great advantages which have accrued from the employment of men of the highest scientific culture in the conduct of those enterprises—that, the days are past when an engineer can acquit himself respectably by the aid of mother-wit alone, or of certain constructive instincts, which have been almost the only guides of engineers and manufacturers, even down to quite recent times.

This Institution has already shown, in the regulations not very long established with respect to the qualifications of the Student-class, that it is alive to the fact that some scientific training is desirable in a profession in which the lives of human beings, to say nothing of their property, are dependent on the knowledge and skill possessed; that in the vast works now undertaken a good deal more than intuition is necessary, and that scientific knowledge and training are attributes which the public have a right to demand of its engineers. So strongly does this feeling exist that it has assumed practical expression in the form of Science Colleges, which have been founded, either by individual liberality or by subscription, in every considerable town in the provinces, completely eclipsing London, where the movement first began, but where it languishes for want of adequate support, except, indeed, in the noble endowments of the City and Guilds schools, and the Government establishments at South Kensington.

The old arrangement must come to an end, we must not be deceived by our past experience when, supported by our immense and exceptional natural advantages, it may be admitted that our rough system worked fairly well.

In those days, and the practice survives even now, a public school-boy was taken into an engineer's office or into a factory, and there he exchanged his small store of dead languages for an equally slender equipment in science, acquired as it best could be, while following the routine of his master's practice, the said master being himself but scantily provided with anything more tangible than experience, an endowment which, from its very nature, is incapable of being communicated fully, and which can only be acquired by the professional activity of a lifetime.

It has often been my good fortune to discuss with Continental engineers the relative advantages of the English and foreign systems of training. The foreign engineer had, as a rule, an admiration for what he called our practical methods, and lamented

that, in his own country, training was almost exclusively theoretical; but I think that the superior education of the operatives abroad was not sufficiently recognized—the managers, the foremen, the draughtsmen, and even to a great extent the mechanics and other operatives, had had the advantage of technical training even before they began to acquire mechanical dexterity, so that the want of practical knowledge in the leaders has been met by a fair amount of theoretical knowledge engrafted on the practical experience of the followers, and it is incontestible that this combination is producing results as advantageous to our foreign competitors as it is disastrous to our own industries.

With rare exceptions, in this country, has there been even a slender amount of theoretical knowledge imparted to the various grades of employment; it is only during the last few years that Science Colleges and technical education in schools and People's Palaces, are beginning to bring our operatives up to the level of our foreign friends, but, unfortunately, too late to retain that pre-eminence which we at one time could claim, and, I fear, placed too much confidence in; and moreover, a new danger has arisen in the circumstance that popular scientific education has taken a one-sided direction, that of mechanical or technical knowledge alone, so that, though the operative approaches his work with increased intelligence, he remains unfit to reason out the great economic problems on which his own welfare and that of the nation depend.

It is a matter of extreme surprise to me that so little attention is paid to the science of Political Economy, that not only the mass of the people, in whose hands the voting power now lies, but even, in a great measure, the representatives whom they elect, have no systematic training in, and are grossly ignorant of, the principles which lie at the root of national prosperity. The further misfortune follows that politicians of the highest position do not scruple to trade on this ignorance, or to pursue a course which, in its consequences, is as bad—being ignorant themselves they strive to lead the ignorant, and set the operative against his employer and against society in general. The cheapness of newspapers, their wide diffusion, and their blind, not to say reckless advocacy of popular fallacies acting on the ignorance, prejudices, and discomfort, if not suffering, of the operative classes, are giving enormous power to trade organizations, whose avowed object it is to improve the earnings and social standing of the operative at the expense of, or at any rate without regard to, the interests of every other class in the community, and this is to be accomplished

not by encouraging education, not by advocating thrift and temperance, not by urging the workman to improve his mechanical dexterity, the thoroughness of his work and the amount which he produces, but by holding out visions of shortened hours of labour, by compelling a minimum of pay which will enable him to live in comfort, of systematically restricting the amount of work done by each individual, even in the shortened day, all under the fatal illusion that by such means a greater number of men will find more remunerative employment.

The employer is usually credited, by the trade leaders, with accumulating wealth without effort, risk, or anxiety, by the slavish labour of his operatives, while the proofs to the contrary, so easily to be obtained in the slender dividends declared by most industrial enterprises, and in the records of the Bankruptcy Courts, are steadily kept out of view.

There would be no fault to find with the new class of professional agitators, who live by the discontent which they foment, were they, and the Unions which they manipulate, to contribute in the smallest degree to the obtaining of that work and of those orders, in the execution of which the wage-earning portion of the community have their being. This, the most difficult part of every commercial enterprise is left to the much-abused capitalist, so that the absurd and impossible system is fast asserting itself, that professional skill, mercantile ability and capital shall obtain the work, and run all the risks of design, execution, and financial security; but that work shall be carried out according to rules which self-constituted and perfectly irresponsible bodies choose to impose. The smallest acquaintance with the principles of political economy would demonstrate that such methods must end in ruin, that they are utterly incompatible with our policy of Free Trade—a system which is perfectly reasonable and proper if thoroughly carried out, and which certainly never contemplated the protection of one particular class, and that, not by edict of the State, but at the bidding of self-constituted tribunals whose claims amount to this:—that there shall be free trade in all products which the operatives require to buy, but the strictest protection as to all that they have to sell, namely their labour, and whose ultimate methods are violence, and the coercion of all who differ from views which many intelligent but timid workmen know to be at variance with the true interests of their class.

Under all this lies the socialistic idea of equality in the condition of every member of the community, an idea which Political Economy demonstrates to be utterly Utopian and impossible.

Since the creation of mankind the differences in social position and in material comfort which follow naturally from the endless variations of mental and bodily powers in men, have existed, and, in spite of many abortive attempts, more or less violent, to establish equality, will exist for ever;—for it seems to me that the doctrine of Carnot with respect to heat-engines applies by analogy to the question of national prosperity. To obtain mechanical power from a source of heat there must be a fall of temperature, and the greater that fall is the more efficient will the engine be—a dead level of temperature simply means extinction of energy and of life. To ensure active trade and prosperous manufactures there must be a fall of money or of its equivalent from the wealthy to the comparatively poor, the one class is absolutely essential to the other; the prosperity of the community is bound up in the existence of these differences, and a dead level of wealth would be a dead level of poverty, which would end, as a state of uniform temperature must end, in absolute stagnation and death.

However much we may regret the inequality which exists in the distribution of wealth and comfort, it is just as much a law of nature as the unequal distribution of warmth, of sunshine, or of rain, and seems to me to follow naturally and inevitably from the endless variations in the physical, moral, and mental powers of human beings, and, therefore, to be as unalterable at the bidding of man as these attributes are. It only remains for us to recognize the fact, to make the best of it, and to avoid the gross wickedness of attempting to delude the poorer and more ignorant members of the community by incessant representations that it is the greed and selfishness of the wealthy which keep them low.

If the so-called “working man” be the embodiment of all that is needed for the industrial prosperity of a country, and if the possession of capital and the far wider consequence, the existence of credit, be a crime, why does he not arise in his strength and exhibit the faculties of combination which are so well illustrated in the trades unions, and establish engineering works, and manufactories, or undertake engineering enterprises from which he will be able himself to reap the golden harvest which the capitalist and the shareholder are supposed to gather, and who thereby excite his envy and arouse his hatred. The reason is very obvious.

Saturday night comes with unfailing regularity, and the week's wages must be met; work has to be found, usually at prices to be calculated beforehand, and when obtained, contracts do not always go on smoothly; engines and machines will not always

work; accidents will happen; long credits must be given; and those men who possess the talent and education to originate and the skill to administer, are comparatively very few, even in this land of enterprise, and have their value, which it is too much to expect that they will not take advantage of; while the buildings, machinery, stock and floating money, which form the capital—of the true nature of which such terrible ignorance exists—are absolutely valueless without the skill and the industry necessary to obtain remunerative employment; while the matter of credit, on which so large an amount of our activity depends, is almost a personal matter, and could never be commanded by a body of operatives, however respectable.

Co-operative enterprises are much talked of just now, and in some cases of shopkeeping have been successful, because such undertakings have been conducted on cash principles and under the ordinary conditions of trade. But co-operative manufacture, in which the workmen without capital are to share the profits are simply impossible, because they have no means of sharing the losses. It is singular how, in discussing enterprises to be conducted on the profit-sharing principle, the necessity of providing for loss-sharing is left out of consideration, though the grim reality asserts itself quickly enough when attempts are made to start manufactures, even on the smallest scale, without capital, for the unfortunate co-operatives soon discover that obtaining orders is a much more difficult business than executing them, and that capital is indispensable to command regularity in the conduct of work and in the payment of wages.

In deference, I presume, to the immense numerical importance of the operative classes, politicians are vying with each other in supporting the impossible claims put forth—claims which, if conceded, will only precipitate the ruin of the class they profess to benefit, and which already, in the form of what may be termed benevolent legislation in favour of the operative, is heaping up elements of cost which our productive energy is unable to bear. The absurd cry that manual labour is the sole source of wealth has been well combated by that acute reasoner, Mr. Macfarlane Gray, who, in a recent discussion on the labour question, happily compared the body politic to a tree. The popular belief is that plants are nourished through their roots, which for that reason are believed to be the all important parts, while the leaves are mere ornaments, enjoying the upper air and sunshine and profiting by the work done underground. But a juster knowledge, one of the fruits of abstract investigation, tells

us that the roots are mainly useful in holding the tree erect, and have comparatively little to do with providing the materials for building up its structure. It is the leaves which form the great laboratory in which the main components of the plant are extracted from the region where superficial observers would least expect to find them—namely, from the atmosphere. He compares the roots to the operatives' part of the community; the trunk and leaves to the monetary, the scientific and the commercial part which drew from far and wide that which is necessary to keep the growth advancing and maintain it in health. The roots may just as well claim to be the sole sources of life in the tree as the operatives may claim to be the only producers of wealth, and conversely the leaves could, with as much reason, consider themselves as the only essential portion of the plant as the merchant or the capitalist claim to be independent of the operatives. Each grade in the body politic is essential to the other; it is an axiom that there can be no degrees of comparison between essential parts; and those who, from ignorance or from interested motives, persistently preach the doctrine of the superior importance of the "masses" over the "classes" are inflicting a deep injury on the prosperity of the country, and especially on those whom they so grossly flatter.

It seems to me that a very great national danger is being incurred by this systematic neglect of Political Economy—an abstract science which had its origin in this country, but where its teachings are ignored in a manner which must end in disaster, the signs of the advent of which are, I fear, only too plainly apparent.

Even in my lifetime a great change has come over the methods of executing engineering work. During my apprenticeship in Manchester I was associated with workmen—millwrights they were called—perfectly uneducated, but of the utmost intelligence—men whose workboxes contained the tools of nearly every trade and who could handle those tools with dexterity and skill. Before the days of easy communication they were sent away to great distances in charge of works, both extensive and intricate, and executed them, as a rule, with a thoroughness and an intelligence which left nothing to desire. The necessities of the present age have rendered great subdivision of work inevitable, and the action of trades' unions is restricting the range of the workman's acquirements, so that there are but few mechanics left who are conversant with many trades, or whose characters and experience enable them to be as self-contained and trustworthy as

the millwright of old; hence it seems to me hopeless to expect that, in the engineering trades, at any rate, the workmen will ever be able to dispense with the commercially-educated and experienced capitalist and the highly trained scientific staff he finds it necessary to employ.

And let it not be supposed that this, and kindred institutions, have no interest in the question. Our prosperity rests upon the well-being of our members, and that again depends upon the activity of trade and upon the existence of enterprise. But the "dividend grabbers," as investors in industrial enterprises are elegantly called by the foolish and ignorant men by whom the operatives are content to be led, will not embark their money in ventures where there is no prospect of reasonable interest, or where the hopes of such interest are endangered by labour agitations, encouraged, to a great and fatal extent, by political parties, who do not scruple to purchase votes by holding out all kinds of Utopian prospects.

But money must be invested; it cannot, in these days, be hoarded in strong boxes, as it was in Pepys's time; consequently our capitalists will search for outlets abroad, and by promoting industrial undertakings outside our shores, will, through the action of free trade, beat down the value of produce still more, and so further arrest the development of that manufacturing and engineering enterprise upon which our prosperity depends.

One method of combating this, I have pointed out, is the dissemination of sounder views on Political Economy concurrently with the spread of technical education. The other course is to pay more attention to abstract science and to devote more time to the study of what is going on around us in the world. I am afraid that the nature of the education of the wealthier classes in this country is responsible for a good deal of the insular conceit and exclusiveness with which, in spite of our peripatetic tendencies, we are still afflicted. Classical education, no doubt, has its merits, and is well suited to a large section of the community; but in these days of the extensive scientific knowledge which a competent engineer is bound to acquire, the universal application of the method seems to be a mistake, while I cannot but think that the acquisition of modern languages and scientific study are fully as efficient in training the minds of the young as they are incomparably more useful in the battle of life afterwards.

Nor am I singular in this view. Successive Presidents of this Institution, in their inaugural addresses, have dwelt upon the cardinal importance of the education question, and within the last

two or three years the Council has exacted conditions as to liberal education and scientific training from the candidates for student membership; which cannot be regarded as otherwise than happy; and without doubt, before very long, even in the higher grades of membership, evidence will be demanded of special attainments in abstract science which are now so accessible to all in every part of the Kingdom. I do not, for a moment, lose sight of the practical training, which I consider so essential to the qualifications of an accomplished engineer. I recognize the fact that there is a tendency in the pendulum of knowledge to swing to the opposite extreme, and of the rising generation of engineers to wax conceited, and to imagine that the diplomas obtained at Universities are guarantees of fitness to commence professional work at once. And here again I am in accord with many Past-Presidents, who, in their addresses, have dwelt on the importance of practical training. I hold that the engineer's education should begin earlier, even at school, and should embrace those branches of knowledge which, in our great public schools, are still, in a great measure, ignored, or taught in a half-hearted manner, more as a concession to the utilitarian spirit of the age than as an essential equipment for many professions.

But nothing, save bitter experience, will alter the course of events. It seems to be the fate of peoples to attack social problems from the wrong end, to solve them by the painful and dilatory process of trial and error, rather than by means of investigation based on first principles. And this method is commonly applied to engineering problems also. Random trials, as a rule, are the methods by which great results have been achieved, while the application of the scientific principles involved have been left to other heads long after the results sought have been attained at much needless cost, and by much unnecessary expenditure of labour and of time.

It is not often that a genius of the order of James Watt rises in the mechanical world. Up to the time when the University of Glasgow required its model of a Newcomen engine to be repaired, the "fire-engine," as it was most properly called, was being slowly developed without any exact knowledge of the properties of the agent by means of which the heat generated by the combustion of fuel was converted into work, and this in spite of the circumstance that such a master mind as that of Smeaton had been directed to perfecting the new method of utilizing the potential energy of fuel, and of applying it to engines of large power, and on an extensive industrial scale.

The bent of Watt's mind was characterized by a love for abstract science, and it was, no doubt, for that reason that he abandoned his father's business and took up the profession of a philosophical instrument maker, in the pursuit of which he naturally came in contact with the meagre knowledge of physical science of the period, and with men eminent in the world of learning and of research.

The lucky chance which presented itself of having to put in order a working model of a Newcomen engine, illustrates in an interesting manner how, in pursuance of his business, he quickly executed the necessary repairs and alterations, and afterwards, at greater leisure, attacked the problem which the failure of the model presented, from the theoretical side, but soon found that the then state of knowledge did not afford the means of explaining the failure, and compelled him to set about the determination of such elementary data as the specific volume of steam, the latent heat of evaporation, and the law of tension of steam under varying temperatures. In the astonishingly short period of two years, and with the rudest and cheapest apparatus, he had furnished himself with the abstract knowledge required for explaining in a definite manner the action of the steam-engine, and he had no difficulty, as soon as his theoretical ground was sure, in determining what mechanical arrangements were necessary to realize the conditions imposed by science. From investigations, apparently of an abstract or non-practical character, sprung at once the separate condenser, the closed cylinder and the equilibrium working of a single-acting engine, the steam jacket, the air-pump, the theory of expansive working, the function of the momentum of the moving parts, and the exact calculations based on first principles by means of which the proportions of engines could be fixed, and the quantities of steam, water, and of fuel calculated. Watt, of course, was a born mechanic, as well as a seeker after physical knowledge. The workshop in his private house near Birmingham, happily preserved to this day as he left it, shows that his mind was ever bent on mechanical contrivances which his own hands were skilful enough to carry out; his valve-gear, the stuffing box, the parallel motion, the governor, are all instances of that happy blending of mechanical skill, and of scientific research, which must ever mark the qualifications of a great mechanical engineer.

A contrast to Watt's achievements is the singular history of the development of iron and steel bridge building, which necessarily followed the introduction of railways. Watt felt the want of first

principles by which to shape his actions, and set about discovering them; but the principles which underlie the determination of stresses in braced structures, such as roofs and frameworks of various kinds, as well as those in solid bars subjected to the action of transverse forces, have long been known; and early in this century Navier made them the subjects of lectures at the *École des Ponts et Chaussées*, yet engineers in this country seem to have been but dimly aware of them, or, at any rate, to have made little use of the knowledge which was at their disposal. It is difficult, from the published histories of such enterprises as the Conway and Britannia bridges, to arrive at any conclusion as to the extent of knowledge, or rather ignorance, which existed among engineers before these works were commenced. It is probable that some of a specially scientific turn of mind, but who were not in conspicuous practice, had a deeper insight into principles than the men whose great natural genius and knowledge of affairs placed them in prominent positions in the great railway enterprises of the day. It is sufficiently evident, however, from the long series of purely tentative experiments by which the proportions of the Conway and Britannia bridges were determined, as well as from the singular vagaries to be noticed in the smaller bridges of that day, that only the haziest ideas of the disposition of stresses, and of the functions of the component members of girders existed. This naturally led to timidity as to the capacity of girders to carry, unaided, the loads it was sought to impose, and induced a preference for masonry or for suspension bridges, with respect to which much wider experience was at command.

In the experimental investigations of the time, the function of the web or vertical member of a girder was completely ignored, for it was looked upon merely as the means of keeping the top and bottom flanges in their relative positions, while the essential difference in effect of a uniformly distributed load, or of a rolling load, as compared with a load concentrated at the centre, on the vertical member of a girder, and even on the flanges, appears to have been overlooked till made evident by the results of experiment; and the grave doubts which arose as to whether the girders of the two great tubular bridges could be made self-supporting are apparent to this day in the preparations made in the piers and abutments for the introduction of auxiliary chains. Yet the principle that a force cannot change its direction unless combined with another force acting in a direction inclined to it, was perfectly well known, and should have led to the discovery that it is only by diagonal stresses in the vertical members that the load resting on a beam can be

transmitted to the abutments, or be made to produce effects at right-angles to its own direction in the flanges; and that the stresses due to loads concentrated at the centre were very different to those arising, both in the vertical web and in the flanges, from the action due to a load distributed in a given manner along the top or the bottom flanges, and that a rolling load would produce effects peculiar to itself.

The girder with diagonally braced webs, or the lattice girder, as it is commonly called, appears to have had its origin in Ireland; at any rate it was in that country that it received its earliest and chief development; but at first, as illustrated by the bridge which used to carry the Dublin and Drogheda Railway over the Grand Canal in Dublin, it was a mere attempt to substitute for plate webs an arrangement of flat bars sloping in opposite directions, placed very close together, and having the oppositely inclined bars connected at their intersections by countersunk rivets.

This was naturally a very wasteful arrangement; but soon, in the hands of C. H. Wild, Barton, Bow, and Stoney, the true principles began to assert themselves, and Mr. Barton's Cusher River bridge, of 70 feet span, on the Great Northern of Ireland Railway, was probably the first example of a lattice girder in which the cross-sections of the members of the webs as well as those of the flanges were correctly proportioned to the stresses imposed by a rolling load. This comparatively small bridge was followed by the Boyne viaduct at Drogheda, which must ever rank as a signal illustration of the successful application of abstract principles to a great work by men who were capable, not only of appreciating them, but of following their guidance in a practical manner. The only experiments made during the preparation of the designs were those instituted to ascertain the power of resistance of the proposed braced diagonals to a compressive stress.

The wrought-iron portion of the viaduct consists of three spans, the main girders of which are continuous; and the points of contrary flexure in the middle, and larger span, were determined by direct calculation, the correctness of which was demonstrated in the actual structure by setting free the plates of the flanges at the points indicated,—in one girder at the top only, but in the other both at the top and bottom, and by observing the opening and closing of the plates so disunited when the land ends of the girders forming the side spans were raised or lowered.

Mr. C. H. Wild appears to have been the first to demonstrate correctly the distribution of stresses under any disposition of load

in the Warren girder, a form of beam in which the web is composed of a single system of diagonal bracing inclined at an angle of about 60° . In the museum of Trinity College, Dublin,¹ there has existed since, I believe 1854, a model of a Warren girder, 12 feet 6 inches long and 12 inches deep, in which the tension members both of the flanges and diagonal bracing are so arranged and articulated that any one section can be taken out and a spring balance inserted, by means of which it can be demonstrated that the stresses calculated for any disposition of load do actually arise.

Since 1848 the supremacy of theory over rule of thumb has gradually but surely asserted itself, though, at times, the want of common sense and experience in the application of abstract principles, as well, perhaps, as ill-judged efforts to produce cheap structures, has led to disasters quite as serious as those which arose from want of theoretical knowledge; and in this respect the competent and successful engineer will still show himself as the man who in his work is careful to make theory and practice walk side by side, the one ever aiding and guiding the other, neither asserting undue supremacy. This course, in its highest development, we may I think assert is that adopted by our leading engineers, with the result that this country may claim the honour of such a structure as the Forth Bridge, for the design and construction of which no tentative experiments were needed, though the form and mode of construction were very special, if not absolutely new; and the dimensions, both in span and height, so gigantic that the authors of the design could have derived but little aid from previous experience.

The history of scientific research teems with instances of discoveries which at first seemed to have had no practical value, but which nevertheless have ultimately proved to be of the utmost importance to the engineer. Notwithstanding such experience, and even in these days, there are so-called practical men who are utterly intolerant of either time or money being devoted to investigations which seem incapable of bearing immediate fruit. Many examples might be cited, for instance: the changes of temperature which occur in many chemical reactions were merely noted, at first, as interesting accompaniments to such reactions; but, by degrees, it was perceived that the amount of heat evolved or absorbed in each chemical change was a constant and definite quantity, which was capable of exact measurement, and in process

¹ This model was sent over and exhibited at the lecture.

of time the thermal values which characterised a vast number of chemical changes were determined, and are now considered of cardinal importance in many industrial operations, and constitute the science of thermo-chemistry.

At the same time the total heat of evaporation of water and of other substances was ascertained with great precision, so that it became possible to judge of the efficiency of a boiler, for instance, when the rate of fuel combustion and that at which the water was heated or evaporated were known, by calculating the proportion which the heat imparted to the water bore to that produced by the combustion of any fuel of which the chemical composition had been ascertained, and from which the heat capable of being developed could be calculated by general rules, and thus researches in the chemical and physical laboratories have had the ultimate effect of placing the theory of the steam-engine on a firm basis.

One practical consequence of the exact knowledge which every competent engineer now possesses on this subject, or can easily obtain, is that inventors have ceased to squander their time and their means in seeking for impossible high boiler duty, and the public is no more entreated to try contrivances which are to save at least 50 per cent. of the fuel they use, because inventors know that the testing of boilers is now usually carried out by experienced and educated men, who, by very simple and inexpensive trials obtain the data by means of which they can calculate with certainty how much scope for improvement actually exists.

Still more remarkable perhaps is the application of thermo-chemistry to the complicated reactions in the blast and regenerative furnaces, and the valuable conclusions arrived at in consequence by such thorough and patient investigators as Sir Isaac Lowthian Bell, Sir William Siemens, Charles Cochrane, and others who have succeeded in equating the heat-units resulting from the oxidation of fuel to the ultimate thermal results of the decomposition of the ore and fluxes, showing thereby the limits of economy which the ironmaster may hope to reach, and the proportions of the furnaces in which his expectations may be realized.

No less valuable have been the fruits yielded by the discovery of the great law of the Conservation of Energy, and by the recognition of the fact that, though energy cannot be destroyed, it may be made to assume various forms, and may be rendered either dormant or active. The sun's rays, æons of ages ago, during the dense vegetation which characterised the period of the coal measures, expended their energy in tearing asunder the carbon and oxygen of the carbonic acid so sparsely distributed through the

atmosphere, and in storing the carbon, thus endowed with potential energy, in the deposits whence we now derive our coal supplies. By suitable arrangements this dormant energy is quickened into that quality of motion which we recognise as heat, and which, setting into sympathetic vibrations the material of the furnace-plates and smoke-flues of boilers, operates on the surrounding water, the molecules of which, under this influence, assume the more extended movements of the highly elastic substance which we know as steam. The products of combustion, on the one hand, are restored to the atmosphere, their remaining store of heat is slowly dissipated, while the carbonic-acid gas produced in combustion is again ready to present itself, in the green leaves of plants, to the decomposing action of the sun, and by that means the carbon and the oxygen become once more sources of heat. The steam produced, on the other hand, communicates its molecular motion to external bodies in various heating operations, in the visible motion and force of the steam-engine or into the slower dissipation through space or over the earth, whereby it is again condensed to water and returned to its normal condition, while the energy, for the exhibition of which, Carnot has taught us, steam was the mere agent, becomes transformed into masses of water lifted, into air compressed, into electrical currents generated, into mechanical work done, or into the heat developed by friction; but the general tendency is towards dissipation under the form of heat into space, the waste being made good by the stores of heat poured on to our planetary system by the huge and mysterious body which is its centre. Whence this enormous and apparently unfailing supply of heat is derived has been, and still is, the subject of most interesting controversy, the upshot of which seems to be that the heat developed by the shrinkage of our luminary and by the fall on to its surface of meteoric matter is sufficient to keep up the supply at any rate for many thousand years.

But modern investigators, and, most of all, engineers, are not content with vague statements such as I have just made; they hold with the motto of the ancient Society of Civil Engineers, "*Omnia in numero pondere et mensura*," and they are therefore greatly indebted to Rumford, Carnot, Davy, Mayer and Joule, who not only showed that heat was a "mode of motion," but determined by tedious and delicate experiments its mechanical equivalent.

And what is now the result?

When examining heat-engines or other applications of heat in the arts, the engineer collects the apparently aimless work of half a century, and of many minds, and finds himself able to construct

a balance sheet in the manner first adopted, I believe, by Sir Frederick Bramwell,¹ by which he can show on the Dr. side, to a fraction, the quantity of heat he has received, and on the Cr. page, with astonishing precision, the manner in which that heat has been expended. This method of treatment is not only lucid, but it is self-checking, and it points out exactly how much heat has been uselessly dissipated, and consequently in what direction improvements may be made, and it indicated, further, the limits within which it is alone possible to make advances in economy.

These general principles apply even to the conversion of heat into the work done in the bore of a gun. The enormous pressures which require to be developed in order to impress high velocity on the projectile in the necessarily limited length of the barrel, the shortness of the time of action, and its violence, render it extremely difficult to obtain accurate and trustworthy records of pressures along the chase of a gun by direct methods; but by invoking the aid of the chemist and of the physicist in first ascertaining the properties of the explosive, that is to say, the specific volume of the gases, the quantity of heat evolved during combustion, and the specific heat of its products at high temperatures, it becomes possible to calculate curves of mean pressure which will account for the energy imparted to the projectile and to the expelled gases, although the question of abnormal local pressures, due apparently to the mode of ignition of the charge and the rate at which explosion is propagated through it, will not be revealed. This process is made the easier, in the case of smokeless explosives, because the products of combustion are wholly gaseous and retain that condition till expelled from the bore.

One of the loftiest of abstract conceptions relating to the structure of the universe, the product of many acute minds of this century, is the imagining of a substance of infinite tenuity but of immense elasticity, which permeates all space and every substance. It cannot be seen, or felt, or weighed, its composition is unknown, it cannot be pumped out of a closed vessel, it does not appear to offer any resistance to the motion of planetary bodies, and its existence is only made manifest by its property of transmitting chemical rays, light, radiant heat, electricity, and probably some more recondite forms of energy, at enormous velocity from the remotest regions of the universe and by means of vibrations the nature of which, the astounding frequency and minute pitch, have been determined by mathematicians. It is pardonable in human

¹ Minutes of Proceedings Inst. C.E., vol. lii. p. 155.

beings to disbelieve in the existence of the luminiferous ether, even though the profoundest thinkers and most successful workers of the present day may have all the conviction of Lord Kelvin, who has declared that "it is the only substance that we are confident of in dynamics, the one thing we are sure of is the reality and substantiality of the luminiferous ether!"

But what has the Engineer to do with such speculations, and what does it matter to him how light and heat are transmitted from the sun or from the stars, or by what mechanism heat, magnetism and electricity are diffused over the earth? This question is being answered already in our daily practice, and is destined, no doubt, to receive fuller and more convincing response as time rolls on. I will give one or two instances. The study of the spectrum produced by the passage of light through triangular prisms has revealed the fact that the ordinary rays of white light are of a complex nature, that only a portion of them are discernible directly by the sense of sight or by that of feeling, while the ultra-violet rays can only be seen in their action on Uranium glass, or in the chemical decomposition they produce in certain substances. This knowledge has been of immense use to the photographer, and has, in such hands as those of Captain Abney, assumed a highly practical value. But, further, the spectrum viewed by modern instruments is found not to be continuous, it is crossed by dark, by light, and by coloured bands, which the patient researches of Fraunhofer, Kirchhoff, Huggins, Norman Lockyer, and others, have shown by their position, thickness or colour to characterise certain glowing substances, and by comparison with the spectra produced by heated terrestrial solids and gases, it has been proved that many of the elements in the sun and in the stars are identical with those with which we are familiar on this earth, and this knowledge has served in a striking manner to confirm the correctness of the nebular theory as to the origin of our planetary system, advocated by La Place in his immortal work on the mechanics of the heavens.

Not only have a large number of terrestrial elements been discovered in the sun, but the spectroscope has revealed, to a considerable extent, the order in which they are arranged on the sun's surface, and this leads to the conclusion that at one time a similar order prevailed on the earth, and therefore throws some light on the deep geology of our planet.

One of the practical outcomes of these discoveries has been the theory of Mendeleeff on the origin of petroleum, a theory of the utmost importance to the human race, and to our country in

particular, in view of the inevitable exhaustion of our coal-supplies, for it asserts that petroleum is the product of the action of water on the carbides of metals at high temperatures at no very great relative depths in the crust of the earth, that this production is continually in progress, and that deposits thus actually forming may be reached in many places by sufficiently deep borings. It is somewhat humiliating, when thus drawing attention to the recent rapid advance of science, and to the manner in which the engineer has adapted the discoveries of the abstract investigator to the use and convenience of man, to be obliged to confess how utterly insignificant are human operations with reference to the size of our planet. The deepest mine is a mere scratch on its surface, so that though the theory of Mendeleeff may be true, the question arises whether there be any hope that the wealth inferred to exist may ever be realized, whether the powers of the engineer will ever be so exalted as to enable him to reach those stores of combustibles which that theory supposes must exist in many localities, especially in those where the surface has been much shaken by primeval convulsions, and where the deposits may, therefore, be expected to lie at relatively short distances below the surface? In view of recent progress in mechanical skill, it certainly would be rash to say that borings of immensely greater depth than any that we are as yet acquainted with will never be made, for if accumulated evidence as to the correctness of Mendeleeff's views together with the ever-increasing cost of fuel, shall hold out hopes of success, enterprising men will be found ready to embark their means in undertakings, the risks of which would not seem to be more formidable than those which surrounded the laying of the first Atlantic telegraph cable, and the rewards of success in which would be incomparably greater.

But the spectroscope is doing yeoman's service nearer home, and producing practical results of the greatest importance. It is one of the most delicate instruments for chemical analysis. By its indications in 1860 Bunsen discovered the metals Rubidium and Cæsium in the waters of the Dürkheim mineral spring, though the quantities were so small that only from 3 to 4 grains of the chlorides of the metals existed in a ton of water. With the composition of metals used in the arts the engineer is especially concerned, and it is now well known that extremely small additions of foreign substances produce momentous effects. The influence of small quantities of arsenic, of lead or of bismuth on copper; of carbon, of phosphorus, of sulphur, of manganese, and of silicon and other substances on iron are extremely practical questions;

and every engineer who has examined the properties of materials seriously, acknowledges that the influence of a foreign substance on the mechanical properties of a metal bears no relation to the minuteness of its quantity.

The researches of Roberts-Austen, of Osmond, Le Chatelier, and others, are slowly, but it is hoped surely, establishing laws by which the relative atomic volumes of ingredients will become a guide to the nature of their mutual interaction, and it seems probable that spectrum observations which are of such value in gauging the purity of the materials dealt with, will come in aid and in support of the indications given by automatically traced curves of rates of cooling, which have given such a deep meaning to the phenomenon of recalescence, a property of iron and steel which for many years remained a mere laboratory curiosity.

But the undulatory theory of the transmission of radiant energy has an important bearing on the molecular constitution of matter. All substances, according to modern views, are built up of atoms or of molecules endowed with more or less motion of various kinds, and this implies that there is room for such motion, and explains what used formerly to be classed as one of the properties of matter, namely, porosity. Clerk Maxwell, Clausius, Lord Kelvin and many others, have endeavoured to penetrate into the structure and properties of the molecules and of the ultimate atoms, and the subject is of so recondite a nature as to be worthy of such minds; but without attempting to discuss the theories which have been advanced, it is clear that heat plays an important part in the relations between the atoms and molecules, and that that heat is communicated unceasingly, though, perhaps, often indirectly in the form of radiant energy emanating primarily from the sun. As long as temperature remains constant, all other things being the same, no change occurs, but with changes of temperature, changes in the energy of molecular motion take place, and when these pass certain limits, critical states are reached in which additions of heat cease to cause a change in temperature, or even a change of volume, but are expended in very large relative quantities in either changing the nature of molecular motion or in greatly extending it. So we have the commonly accepted three states of matter, solid, liquid and aeriform; but it seems to me that there are other states also, such as the critical condition depending upon temperature and pressure, in which the substance is neither liquid nor gaseous, solid nor liquid, and which has been investigated for many substances, and is exceedingly pronounced in carbonic acid. But many bodies, including metals and their alloys, may exist in

more than one form; sulphur, for example, assumes two allotropic states, but at ordinary temperatures and in a comparatively short time the one condition passes into the other. Mr. Addenbrook has recently prepared an alloy of aluminium and nickel, which when freshly made possesses considerable tenacity, but which, after a few hours, crumbles into powder. The researches of Osmond seem to show that pure iron also can exist in two states, one very hard—the other soft; and it is more than probable that these states merge into each other under certain conditions of heating or cooling, or under the influence of foreign substances. There can be no doubt that steel also, in course of time, undergoes molecular change at ordinary temperatures, and possibly under the influence of strains produced by internal stresses due to unequal rates of cooling. It is a common opinion, based on experience, that tool steel should not be used as freshly made, but should be kept some months; and the same precaution applies to dies used in coining and similar operations, and to armour-piercing shot, both of which, having been hardened by necessarily unequal and rapid cooling, either accommodate themselves to the stresses engendered by slow changes in the motion of the molecules or fail spontaneously even after months of repose. Glass undergoes similar changes, and generally materials which have been severely strained either by the external application of force, or by heating, will only gradually recover their normal condition. This has been beautifully demonstrated by Professor Hughes, with the aid of his induction balance, on specimens of the narrow steel ribbon used in the manufacture of Longridge wire-guns. A number of specimens recently submitted to him showed a remarkable uniformity of structure, but when heated to only 100° and examined immediately on cooling to the normal temperature, a distinct change was observable, yet after a few hours' rest the material returned to its normal state. If such changes are measurable in ribbon $\frac{1}{4}$ in. $\times$ $\frac{1}{16}$ in. in cross section, what may not be the molecular conflict in large masses? These may be produced by alternations of stresses as well as by changes of temperature, and point to the necessity of assisting the molecules and atoms to adjust themselves or to return to a normal condition by raising the temperature of the substance to about the point indicated by b on Chernoff's scale, below which no change in the nature of crystallization takes place, no matter how slowly the mass is allowed to cool. This principle is recognized in many ways in the arts. In drawing wire or in solid drawn metal-work, such as tubes and cartridge-cases, periodical annealing must be resorted

to, moreover experience has shown that crane-chains, for example, should be annealed from time to time if they are to be used with safety; and Mr. Webb has adopted, with the best results, the plan of treating in a similar manner the moving parts of his locomotives after they have run a certain number of miles.

I feel convinced that the frequent disasters with screw-propeller shafts, especially after they have been some time in use, arise from the failure to recognize the practical bearing of the tendency to molecular change under the influence of strain and temperature. A propeller shaft is subject to constant variations of stress due to the action of the cranks of the engine, to similar variations caused by the inertia of the screw, and again to a totally different set of stresses which may often be alternately tensile and compressive, due to the wear of the journals and to the working of the hull. The remedy, I feel convinced, lies in the periodical annealing of the material which must, of necessity, be so hardly used.

I think that it is now generally acknowledged that the luminiferous ether is also the medium by which electrical energy is transmitted by some kind of vibratory motion; hence the ease with which heat or mechanical work is transformed directly into electric currents in the thermopile, or in the frictional electrical machine, and the reasonableness of the great generalization that we are living on a huge magnet—the poles of which are not far from coinciding with the poles of the earth. To what purpose are the endless observations on the deviation and dip of the magnetic needle which are so assiduously carried on by every civilized nation, and what interest have engineers in the painful labours of those daring explorers who set up their Observatories amidst the endless ice and the darkness of the Polar regions?

Let such a questioner, if there be one, study the construction of the mariners' compass, and especially in the improved form introduced by Lord Kelvin; let him compare the blind groping after correction for the local attraction of the ship with the beautiful and simple theory which has rendered that correction not only easy but readily adapted to changes in the ship's position in the world; he will find that there is not a more striking instance of the profoundest abstract knowledge blended with the power to turn it to practical use, than in this and in so many other labours of the distinguished man whom I have named more than once, and whom this Institution is proud to number among its honorary members.

I will not dwell upon the wonderful results of which we are

to-day reaping the benefit, and which have arisen from the application of the most profound scientific knowledge to the problems which arise in the generation, storage and application of electricity, to the transmission of power, to telegraphy, and to lighting, but I would draw your attention to a startling consequence of the undulatory theory in the power which exists of exercising influence, by what is termed induction, at great distances. Animated by the conviction that electric energy was transmitted in the same manner and by means of the same all-pervading medium as radiant energy, and that the distance to which its effects would reach should be unlimited, though the appreciation might be a question of the delicacy of instruments, Mr. Preece has succeeded in sending messages by Morse signals across the Bristol Channel between Lavernock and Flatholme, a distance of over 3 miles. The electro-magnetic disturbances were excited by primary alternating currents, having a frequency sufficient to generate a low musical note in a telephone, in a copper-wire 1,237 yards long, erected on poles along the top of the cliff on the mainland. The radiant electro-magnetic energy was transformed into currents again in a secondary circuit 610 yards long, laid along the island parallel to the first and at a distance of 3.1 miles; the messages were read off on the island through the instrumentality of the induced currents, and the experimenter was gratified to find that the results obtained on the secondary-wire were in complete accordance with the expectation which theory led him to entertain.

Any one who has meditated deeply on the nature of the luminiferous ether and on its universal presence has probably felt that it must also be concerned in the action of the human brain. The mechanisms of the "five gateways of sense" have been worked out by anatomists and physicists, but their researches are incompetent to declare how the impressions sent along the nerves at last reveal themselves as images or perceptions in the mind. Lord Kelvin has discoursed on this matter; he has suggested the existence of a magnetic sense, and has shown that the mind may be influenced independently of the recognized organs of perception. There are undoubtedly occult phenomena which can only be accounted for by the supposition that one mind can interact upon another, even as Mr. Preece's parallel wires acted on each other.

Setting aside the immense amount of calculated delusion and imperfect observations which has characterized animal magnetism, clairvoyance, &c., though probably not more than astrology, necromancy, transmutation of metals, and other delusions, hampered the early advance of physical and chemical science, there still

remains a substantial amount of authentic fact on which argument may be founded. Professor Oliver Lodge drew attention to the matter in his Presidential Address to section A at the meeting of the British Association in Cardiff in 1891, and in the opinion of that acute investigator the subject seems to deserve the attention of scientific societies. The influence of mind upon mind is undoubted, whether between great leaders of men and their followers or between individuals. How comes it that such men as Law, Napoleon, Wellington, Father Mathew, Parnell, Gladstone, Booth, Lesseps, and many others, for good or ill, have been able to exert such marvellous influence over immense masses of men? and how have individuals acquired the power of influencing the conduct of others or of discerning their hidden intentions or actions as shown in well-authenticated cases of what is known as mesmerism and thought-reading? Numerous, too, are the cases of presentiment, or knowledge of events which have taken place at a distance, and about which the person informed has not even been thinking; and there is, again, the whole region of dreams, with reference to which we are in complete ignorance.

I do not think that it is at all a wild idea to imagine that the process of thought or of will going on in one mind may be communicated, like light or heat, to another either by contact and conduction, as in thought-reading, or by awakening induced thought, as when one person is able to establish a powerful influence over another.

The poet frequently penetrates at random deeper and earlier into the mysteries of nature than does the sober man of science. Lord Byron, in two remarkable stanzas in "Childe Harold," alludes to the "electric chain with which we are darkly bound," and, with all the grace and simplicity which characterizes his verse, points out how trifling and accidental circumstances appear to have the power of awakening thoughts and images which we had long supposed buried in oblivion!

It cannot be said that engineers are not interested in this question.

Is it not the occult influence which great engineers exert upon their clients that renders the carrying out of important and hazardous works possible? Where were the enterprizes which have immortalized the names of Brunel, of the Stephensons, of Hawkshaw, of Fowler, of Baker, of Lesseps, or of the daring promoters of the transatlantic telegraph cables, had not these men had the power of communicating unbounded confidence to those who supplied means in such abundance and at such risk!

It surely is desirable to ascertain by what mechanism this singular influence is exerted, and if the key to the mystery be found to lie in the luminiferous ether, it seems to me that large prospects of advantage to the human race present themselves, and we shall have fathomed another mystery of nature, which, on the face of it, does not seem to present greater difficulties than many which have been triumphantly overcome.

It is less than fifty years, for example, since the nature of epidemics and the mode of their propagation seemed to be beyond the reach of human comprehension, and when Pasteur commenced his classic investigations into the causes of fermentation and of contagious disease, no one, I presume, thought that such an abstruse study as bacteriology could ever be of the least interest to engineers, nor would they have thought that the controversy relating to spontaneous generation, which raged so fiercely only a few years ago, could have influenced the science to which they were devoted.

But the triumphant demonstrations of Pasteur, of Lister, of Burdon Saunderson, of Tyndall, and of many other workers at home and abroad have shown that there is no such thing as spontaneous generation; that zymotic diseases, those scourges of animal and vegetable life, are caused by living organisms whose modes of propagation and of travel are being eagerly studied and are day by day being better understood; they have shown that we are no longer fighting at random against an unknown and covert enemy, but are face to face with a subtle foe whose tactics we are rapidly learning to understand. We have discovered that his best allies are to be found in the carelessness of his victims as to cleanliness, to drainage, and water-supply, and that his most formidable enemy is the engineer, who, being guided by the abstract investigations of the biologist and the chemist, can select with certainty the most fitting source of potable water, and can get rid of the sewage of centres of population, not only without inflicting injury on the surrounding community, but very often actually benefiting them by removing existing sources of pollution and by increasing the productiveness of the soil.

The gradual but steady decrease in the death rate and the increase in the duration of human life, the greatly reduced virulence of many epidemics, the total extinction of some, and the means of protecting from their assaults, may be cited as instances of the successful practical application of abstract principles which has not only conferred great benefits on man, but in the end opened up fresh fields of activity for the engineer.

But not alone in sanitary matters has bacteriology produced

profitable results; it may truly be said that the great industries of brewing, of wine and vinegar-making, and many other manufactures, have been placed on a sound footing by the knowledge we now possess of the occult action of ferments and of bacteria; and even in agriculture the true nature of the operations which take place in soil, by which the nitrogenous food of plants is rendered capable of assimilation, is one of the triumphs of the research of these our days. Schloesing, Müntz, Pasteur, Munro, Percy Frankland and others, have shown that one of the most important of plant-foods in the soil is nitric acid, and that this substance is elaborated from ammonia by the action of minute living organisms. The singular fact has been demonstrated that the work is performed by a system of division of labour, one kind of bacterium converting the ammonia into nitrous acid and declining to do any more, when another species takes up the work and produces nitric acid, which presents the nitrogen in a form which can be assimilated by the plant. "Not only," to use the words of Dr. P. Frankland, "is this process of nitrification going on in the fertile soils, but enormous accumulations of the products of the activity of these minute organisms in the shape of nitrate of soda are found in the rainless districts of Chili and Peru, from whence the Chili saltpetre, as it is called, is exported in vast quantities, more especially to fertilize the overtaxed soils of Europe!" But more than that, long and patient research has established the fact that, in certain of the leguminous plants, the same microscopic agency acting in the roots endows them with the power of assimilating the nitrogen of the atmosphere, and by that means makes them the instruments for actually enriching the soil instead of exhausting it.

I have already alluded to the circumstance that the engineer cannot be satisfied with vague statements or with mere abstract opinions. The very nature of his calling implies action; he has to construct, his works must be stable, his machinery must act, his estimates of cost and of the consequences of his operations must come true, and hence he has to make a close alliance with that most fascinating and fruitful of the sciences—mathematics. It is not given to many to possess the peculiar aptitude which leads up to the highest investigation, but neither has the engineer often need of anything deeper than almost elementary knowledge, especially if he gets into the habit of working out the problems that come before him by the graphic methods which are now so assiduously cultivated, and if he will realize that slovenliness in the matter of calculations commonly leads to disastrous

results. Though his attainments may not be high, and though disuse may have made it difficult to wield the power which knowledge, early acquired, once gave him, yet he can always appreciate and put his faith in the great minds which delight in subjecting the theories of physicists to the rigid test of mathematical analysis, and thereby stamping them with the seal of irrefragable fact.

One great quality he must possess, especially in these days when numerous science colleges have rendered high mathematical training of easy access—and that is common sense. There is a tendency among the young and inexperienced to put blind faith in formulas, forgetting that most of them are based upon premises which are not accurately reproduced in practice, and which, in any case, are frequently unable to take into account collateral disturbances, which only observation and experience can foresee, and common sense provide against.

I have endeavoured to show how the history of abstract science, by which I intend to designate the history of researches entered into for the sole purpose of acquiring knowledge of the operations of Nature and of her laws, without any thought of reward, or expectation of pecuniary advantage, has had its reflex in the records of the engineering profession, and how the most recondite investigations, apparently unlikely to have any direct influence on our practice, have, in course of time, become of cardinal importance. I have also ventured to point out how, in these days, the engineer must banish from his mind the idea that anything can be too small or too trifling to deserve his attention. "Nothing is too small for the great man," is, I am told, written over the cottage once occupied by Peter the Great at Saardam. The truth embodied in that legend should ever dwell in our minds; for success, I am persuaded, lies largely in close attention to details.

You may perhaps think that I have endowed abstract science with undue importance, and that I have claimed too wide a domain for the engineer. If this be so, I would turn to the old and faithful Servant of this Institution, in whose honour it has been a labour of love to prepare this discourse, and ask him for his verdict.

You can anticipate his answer! Who does not know how jealous he is of the honour and prestige of our Institution? Who is not aware that he will not concede that any branch of physical science is beyond its province? Nor will he yield to any of the younger societies more than the position of tributary powers. He is glad, as we well know, to recognize, as our children, institutions

dealing with special branches of the profession; he is glad to foster them in every way, and rejoices to see them meeting under the eyes of the Fathers of the profession, whose portraits adorn these walls; but I am confident that he will declare that you cannot touch anything in Natural Science which will not, sooner or later, prove of advantage to the members of this Institution, and which the engineer will not, in time, turn to the moral as well as to the material advantage of the human race.

Mr. HARRISON HAYTER, President, said when he announced that the first "James Forrest" Lecture would be delivered, and that the lecturer would be Dr. Anderson, he stated in effect, if not in words, that it would be difficult to find anyone better qualified to undertake the duty, and from the cordial way in which the announcement was received, there appeared to be a general consensus of opinion in this respect. It had been said that it was unwise to prophesy before the event; but there were exceptions to every rule, and that this was one of them was proved by what they had heard that evening. A first lecture of the nature of the one they had been listening to demanded a lecturer of the highest rank; and in asking the Council to invite Dr. Anderson to deliver it, Mr. Forrest had shown characteristic discernment. The lecturer had treated a difficult subject with marked ability; and, if the lecture could be taken as a type of those to follow, it would augur well for the success of the "James Forrest" Lectureship. On behalf of the members, and on his own behalf, he congratulated Dr. Anderson on this excellent lecture; and he was quite sure they would all join in congratulating Mr. Forrest upon the happy inauguration of the lectureship associated with his name. The members had by their acclamation practically accorded a vote of thanks to the lecturer; but it was his duty formally to propose that "a cordial vote of thanks be tendered to Dr. Anderson for his lecture, and that he be requested to allow it to be printed, with a view to a copy being sent to every member of the Institution." He could only express a wish that a way might be found so that the lecture might be extensively circulated. The remarks Dr. Anderson had made as to Trade Unionism and other socialistic evils ought to be sent to every Member of Parliament, to County Councillors, to School Boards, and to other responsible bodies, so that the mischief done to all classes of society, especially to the working man, might be seen, and the necessity of teaching the truths of Political Economy become apparent to those in authority.

Mr. GILES, Vice-President, said he had much pleasure in seconding the resolution, not only on account of the skill with which Dr. Anderson had dealt with a very difficult subject, but because he had embraced so many branches of science in his lecture as almost to take away one's breath. He had given them also a very good lecture upon political economy, and he only hoped that the gentlemen to whom he referred would have the benefit of reading the lecture, and taking advantage of it in their future career. Fifty years ago English engineers taught nearly the whole world engineering. Since that time, according to Dr. Anderson, foreign engineers had gone ahead of them in science. That might be so; but he maintained, notwithstanding their scientific acquirements, they still wanted a practical knowledge of the work of Englishmen. He had been a great deal among foreign engineers, and his experience went to show that the perfection and finish of English work far exceeded anything he had seen abroad. He hoped this would still continue. It was true that foreign engineers might be more scientific than Englishmen, but he did not think that there were many foreigners whose names would exceed in brilliancy many of those to whom Dr. Anderson had alluded in his lecture. He was quite sure, if the members all applied themselves to the study of the different sciences referred to by Dr. Anderson, they would derive great advantage from having listened to his lecture. He was old enough to remember that fifty or sixty years ago they had not the advantage of the scientific education given at the present time. He had been greatly struck with one remark of the lecturer: "Here again I am in accord with Past-Presidents who in their addresses have dwelt on the importance of practical training. I hold that an engineer's education should begin earlier, and should embrace those branches of knowledge which in our great public schools are still in a great measure ignored." He quite agreed with that sentiment, and well remembered that when he was almost a boy he used to wonder what was the use of so much Latin and Greek. He would only add his thanks to Dr. Anderson for his admirable lecture, and his hope that it might be published for the benefit of the members.

The motion was unanimously adopted.

Dr. ANDERSON said he thanked the President and Mr. Giles for having so kindly proposed a vote of thanks to him, and the members for having so warmly received it. It had been a great grief to him, as he was sure it would be to the members, that Mr. Forrest's state of health had prevented him from being one of

the audience on that occasion. If he had been present he could not fail to have been deeply gratified by the applause, and by the consideration shown for him by the members whenever his name was mentioned. He had received the following letter from Mr. Forrest at Hastings :—

MY DEAR SIR,—I have read, and re-read, your lecture with ever-increasing interest and profit. In the concluding paragraphs you have clothed my views as to the functions of the Institution in far more appropriate language than I can command. They are the views so forcibly expressed by Thomas Tredgold, between fifty and sixty years ago, when he wrote that the scope and utility of Civil Engineering was bound to increase “with every discovery in philosophy, and its resources with every invention in mechanical or chemical art.”

It only remains for me to thank you, and this I do in all sincerity, for undertaking the task of preparing the lecture, and to deplore my unavoidable absence, owing to ill-health, on the occasion of its delivery.—With every respect and regard, I remain, my dear Sir, yours most faithfully,

(Signed) JAMES FORREST.

Dr. W. Anderson, F.R.S.

It appeared, therefore, that the string upon which Mr. Forrest constantly harped whenever it was suggested to him that some Paper was not quite suitable to the Institution, reproduced but the echo of the opinions of one of the masters of the profession fifty or sixty years ago.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2631.*)

**“The 160-Ton Hydraulic Crane at Malta Dockyard
Extension Works.”**

By CHARLES COLSON, M. Inst. C.E., and CHARLES HENRY COLSON,
Assoc. M. Inst. C.E.

THIS crane is situated on the wharf in front of the new factory, on ground enclosed when the Somerset dock¹ was constructed. Loose quarry refuse and mud lay above the surface of the rock, which was met with in the foundations at an average depth of 20 feet below the ground-level; and the rock proved so unsound that it had to be removed to the extent shown (Plate 5, Fig. 1) before solid rock was reached. A large fissure filled with clay was found extending some depth under the old wharf-wall; and the wall itself, although thoroughly sound, was quite unsuited to form part of the foundation of the crane, with its load of 160 tons. The portion, therefore, of the old wall within the foundation was reconstructed, to correspond with the remainder of the foundation below the ground. The excavation for the new wall was carried down to the solid rock, 6 feet below the bottom of the old wall.

The foundation below the ground consists of a solid mass of Portland cement concrete, 56 feet by 53 feet, composed of six parts of hard limestone, three of sand, and one of cement. For the extra depth below the old wall, the proportions were two of cement to three of sand. The flow of water from the back of the old wall, and from the fissure which passed under the dam, prevented the bottom of the foundation trench in the line of the wall being dried; and therefore the concrete, for the first 2 feet in depth, was deposited in bags, packed in regular bond and well rammed down. This made a perfectly sound platform just above the water, on which concrete was deposited *in situ* to the level of the old work. The new section of the wall was faced with hard limestone, to correspond with the courses of the old wall, and backed up with concrete of the same quality as the general mass of the foundation.

¹ Minutes of Proceedings Inst. C.E., vol. xxxiii. p. 352.

The column, above the ground-level, is 50 feet in diameter, and 20 feet high to the top of the curb for the outer roller-path. The face, for a height of $11\frac{1}{2}$ feet, is local limestone masonry, averaging $1\frac{3}{4}$ foot thick, backed with concrete composed as before described, and above this is a ring of limestone masonry $8\frac{1}{2}$ feet high by 9½ feet wide at the bottom, and diminishing to $6\frac{1}{2}$ feet at the top. The curb carrying the roller-path is Cornish granite, dowelled to the course below with stone dowels, and tied together on the top with metal cramps bedded in neat Portland cement. The stones carrying the centre-pivot are granite, bedded on the best local limestone, dowelled and cramped like the outer curb, and further secured by an iron band, 6 inches by 1 inch, shrunk on round the upper edge.

The dam (Figs. 1 and 2) which enclosed the portion of the wall to be reconstructed stood in 28 feet of water, on a sloping rock bottom covered with not more than 2 feet of soft mud, and consisted of a single row of fir piles sawn on the two opposite sides. The gauge piles were driven about 9 feet apart; and each section was wedged up tight. Inside and outside walings were fixed about 2 feet above the water-level, and at 17 feet below; the remainder of the inside walings were fixed with the shores as the water was pumped out. All the piles were driven as far into the rock as possible, but none penetrated more than a few inches, and many of the shoes turned outwards, owing mainly to the very sharp incline of the rock. Caulking on the outside by divers between the sawn sides was only necessary at a few places where the sawing was not quite straight. The soft mud was cleared away at the foot of the piles outside, and the trench filled in with fine cement concrete. This concrete slipped outwards, leaving an aperture about 1 inch wide between it and the piles, which was filled by the diver with neat cement of the consistency of ordinary mortar, stopping all leakage under or between the shoes of the piles. A considerable quantity of water had at first to be dealt with, which mostly came through the fissure in the bottom; some came under and between the pile-shoes, which, however, was stopped as described; and the remainder came from the back of the old work as the old wall was removed. The water passing through the fissure greatly increased after a trial of the engines of H.M.S. "Alexandra," which was moored abreast of the dam. On examination by the diver, the surface of the rock was found to have been cleared of mud by the current set up by the screw. After long search, the exposed fissure was discovered about 25 feet outside the dam; and on its being stopped with oakum and clay, a Pulso-

meter pump, discharging approximately 26,000 gallons per hour, was able to keep the water down.

The boiler and engine-house is at the rear of the new factory, at some distance from the crane site, the connecting-pipes being laid in a covered subway 4 feet by 2 feet. The depth of water alongside, at 45 feet from the coping, is 30 feet.

The crane itself (Fig. 3), including the steam- and hydraulic machinery, was constructed and erected by Messrs. Armstrong & Co. Its maximum working load of 160 tons can be lifted 50 feet at a radius of 70 feet, by means of a direct-acting hydraulic cylinder suspended in gymbals from the jib. For lifting loads up to 35 tons, 90 feet, and at a radius of 75 feet, an additional chain purchase is provided outside the main lifting cylinder, worked by a rotatory hydraulic engine.

The lower frame, jib, stays, counterbalance-box, &c., are constructed of wrought-iron. The lower frame consists of two side girders, 3 feet deep and 22 feet apart, centre to centre (Fig. 5), connected by cross-girders and bracing underneath, and carrying the counterbalance-box at one end, and connected at the other to the bottom of the jib. The jib is constructed of two side members (Figs. 3 and 4), connected by lattice-bracing (Fig. 9), and is tied back to the ballast-box, from the top, by stays, and strutted at the bottom by girders (Fig. 6) connected by lattice-bracing. The structure is carried by, and revolves on, ninety-six bevelled live rollers, 15 inches mean diameter and 16 inches wide (Figs. 7 and 8), working on a lower roller-path of cast-iron planed on the top and bottom, the top being coned to correspond with the bevel of the rollers. The rollers are connected on the outside by links, 5 inches by $\frac{3}{4}$ inch, passing over the ends of the axles, each link taking two rollers; and on the inside, the end of the axle is clipped in a wrought-iron circular frame, connected by bracing (Figs. 7 and 8) to a collar working on rollers round the centre column of masonry.

The centre pivot is fixed to the masonry by four bolts, 15 feet long, extending into the centre chamber, and is made hollow to admit the hydraulic pipes. These pipes are concentric through the pivot, the internal one being for pressure and the other for exhaust. The upper roller-paths are cast-iron segments, about 8 feet long, secured to the under side of the lower frame, two at the front and two at the rear. The counterpoise consists of a wrought-iron box fixed to the rear of the lower frame, and loaded with 480 tons of old iron and stone, sufficient to balance 320 tons, or twice the working load, suspended from the end of the jib.

The main lifting cylinder is of cast-iron in three lengths,

connected together by fourteen $3\frac{1}{4}$ -inch bolts. Its internal diameter is 29 inches, and the metal $3\frac{1}{4}$ inches thick. The piston is cast-iron, and is arranged for hemp packing. The piston-rod of wrought-iron, 8 inches in diameter, is fitted at the lower end with a swivel eye and shackle. A pair of swinging clamps are hinged to the lower end of the cylinder, to prevent the eye on the piston-rod striking the gland if raised too high. A platform is suspended from the cylinder, from which the inlet and outlet valves are controlled, and is reached by a light iron bridge hinged to it and resting on the framework of the jib. Duplicate exhaust-valves allow for the contingency of the failure of one while the load is being lowered. A safety-valve also prevents an excess of pressure in the lifting cylinder. The cylinder is carried in a wrought-iron trunnion-ring, suspended from the jib by four forged-iron links, so that it can be swung in towards the jib when the 30-ton purchase is being used. This movement is effected by a chain tackle and gear worked by the hydraulic engine. A slight movement in a lateral direction is also provided for in the gimbals.

The pressure and exhaust pipes are carried up the jib and down the side of the main cylinder, having hinged joints to allow for swinging. The rotary hydraulic engine for working the 30-ton purchase, turning machinery, and the swinging-in gear of the cylinder, has three oscillating cylinders with gun-metal plungers, $3\frac{1}{8}$ inches in diameter and 14 inches stroke, and is fitted with reversing gear. All the levers for actuating the starting and stopping valves, the clutch and brake, haul gear, reversing gear, &c., are arranged so that they can be worked by one man standing on a platform raised above the lower framework of the crane. The chain for the 30-ton purchase is caught in a wheel with indentations the size of the links, into which the chain is held by live rollers. After passing by this wheel, the chain goes into a chain-box suspended under the lower framework of the crane. A strong brake is provided for lowering light loads. The turning motion is effected through spur and bevel gearing, acting on a toothed rack cast on the outer edge of the lower roller-path; and a brake checks the movement of the crane. All this machinery is placed upon the lower framework of the crane, and is covered in.

The steam-engine for generating the hydraulic power is high-speed and direct-acting, with two cylinders, 12 inches diameter and 15 inches stroke, and lever valves, and two double-acting force-pumps, 3.2 inches diameter and 15 inches stroke. It is mounted on a wrought-iron tank which receives the exhaust water

from the lifting cylinder and hydraulic engine. An automatic hydraulic governor regulates the steam supplied to the engine, so as to keep up a continual pressure of 700 lbs. per square inch in the pipes. There is no accumulator. Steam for the engine is taken from the boilers, which constantly supply steam to the factory, so that the crane is always ready for use.

All the machinery, pipes, and valves, subjected to a working pressure of 700 lbs. per square inch, were tested to 1,400 lbs.; and the cylinder, piston-rod and piston, links, etc., were tested to 320 tons, or double the working load. The cylinder was also subjected to this strain without the piston and rod, and with a cover on the upper end, so as to test the joints before it was lifted into place.

The uprights of the scaffolding used in the erection were made of two 12-inch by 9-inch timbers, strapped and bolted together, with the longitudinal timber passing between the ends of the inner 12-inch by 9-inch piece, which was again connected by a wrought-iron strap. After the rollers and bottom frame of the crane had been fixed on the masonry column, the scaffolding was erected; and the members of the crane, already riveted in long lengths, were hoisted by tackle, and riveted together.

The cost was as follows :—

	£	s.	d.
Concrete, etc., in base below coping, including construction and maintenance of dam, reconstruction of wall, all divers' work, stopping fissures, etc.	5,106	2	0
Concrete and masonry column above coping level, including charges for plant	2,379	13	6
Subway for hydraulic pipes, and foundations for pumping-machinery	194	15	9
Machinery, labour, and stores, and pumping water during construction of foundations	990	17	0
Total cost of foundations , ...	8,671	8	3
160-ton crane complete, including ironwork of crane, its machinery, chains, pumps, pipes, etc., and delivery, but not including erection	14,550	0	0
Total cost of crane and foundations	£23,221	8	3

The Paper is illustrated by a tracing, from which Plate 5 has been prepared, and three photographs.

(*Paper No. 2647.*)

“The River Piers of the Memphis Bridge.”

By GEORGE SHATTUCK MORISON, M. Inst. C.E.

THE Memphis Bridge crosses the Mississippi near the southern limits of the city of Memphis, in latitude $35^{\circ} 8'$ north, and longitude $90^{\circ} 5'$ west, and is situated 232 miles below the junction of the Ohio and the Mississippi rivers at Cairo, Illinois. The authority for its construction was conferred by an Act of Congress, approved April 24th, 1888.

It is the first bridge across the real Mississippi. The Ohio and the Mississippi, though of about equal magnitude where they unite, are streams of very different character. The former river, with its great tributary the Tennessee, comes from a stable country, but is subject to extreme floods early in the year. The Mississippi, whose features are controlled by its greater tributary the Missouri, is subject to less violent floods than the Ohio, but possesses all the uncertain elements of a silt-bearing river; its greatest flood generally comes in June. At Memphis, the river feels the floods of both the Mississippi and the Ohio, though those contributed by the latter river are the more dangerous. The two sets of floods generally result in high water for about one-half the year. The rainfall in this part of the Mississippi valley is abundant, and the climate of Memphis is rather damp. Whilst some snow falls nearly every winter, the amount of frost is insufficient to exercise any essential influence on building operations. During three of four winters while the bridge was under construction, no ice was seen in the river. The position of the river has remained unchanged for a long series of years at the site of the bridge, and, as always happens in such cases with silt-bearing rivers, has become narrow and deep. The low-water width is about 2,000 feet, though the west shoreline has been somewhat variable. Low water, which is of rare occurrence, is 181·76 feet above mean tide-level in the Gulf of Mexico, at the Government gauge 2 miles above the bridge site. At the bridge site it is 181·6 feet, as nearly as could be determined. The highest water-level that has been observed at Memphis occurred on March 25th, 1890, and was 216·2 feet above datum at

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the bridge site. All elevations given in the Paper refer to this tide-level datum.

The requirements of the Government charter fixed the minimum span at 600 feet in the clear, with a channel span of 700 feet. The Secretary of War required the long span to be next to the Tennessee shore, and indicated a preference for a span of 770 feet in the clear. The bridge as built, crosses the river with one span of 790 feet 5 inches and two spans of 621 feet $\frac{3}{4}$ inch between centres of piers.

The three bridge-spans rest upon four masonry piers. Two of these are near the low-water shore lines, and may be properly termed shore piers. The other two are in deep water, and are properly called river piers, and of these the Paper treats. The east pier is known as Pier II, and the west pier as Pier III. The plans of the two piers were prepared in January, 1889. The data from which their character was decided upon were a set of borings which had been made two years previously, and such information as had been obtained during the sinking of the caisson of the west shore-pier. Soundings had shown the bottom of the river to be 145 feet above datum at the site of Pier II, and 160 feet at the site of Pier III. The borings had found clean river sand to 98 feet above datum, near the site of Pier II, and to 108 feet at the site of Pier III. At these levels clay was encountered, which, at the higher levels was somewhat variable in quality, but into which one boring was made down to 61 feet above datum. This clay forms part of an immense deposit known as the La Grange formation, which is about 150 feet thick, and perfectly water-tight. Under this clay lies water-bearing sand or gravel, the outcrop of which is perhaps 50 miles east of Memphis, and at a somewhat greater distance west of that city. The water-supply of the city is derived from artesian wells passing through the La Grange clay into the underlying water-bearing sand, and the wells which have now been driven afford valuable data as to the thickness of the clay. Ten of the wells sunk at Memphis have found the bottom of the clay at depths varying between 6 feet and 93 feet below the datum. A well situated $1\frac{1}{2}$ mile west of the bridge found the top of the clay at 85 feet, and the bottom at 58 feet below datum. A cross-section of the river, showing the material found by the borings and in the caissons, is given in Fig. 1, Plate 6.

It was evident that the foundations must be sunk through the sand and into the clay, and that, whilst it was important to secure a thorough bearing everywhere on this clay, it was probably so compact that difficulty would be experienced in any attempt to

dredge it. Plans were therefore made to meet the four requirements:—(1) The weight of the piers to be limited as much as possible; (2) Provision to limit the scour, at least during the construction of the work; (3) The base of the foundation to be large enough to keep the pressure within safe limits, even on a compressible clay. (4) The method of sinking selected to be the 'plenum' pneumatic process.

To keep down the weights, it was determined to build a high quality of masonry, to diminish the dimensions of the piers to a minimum, and to build the lower portions of the piers hollow, a device which, objectionable in cold climates, seemed prudent here. The method of limiting scour was to carpet the bottom of the river with a woven willow mat, built floating on the surface of the water and then sunk in position by loading it with rip-rap. This device, which is believed to have been originated by the Author, proved successful. When the plans were prepared, it was thought that a satisfactory bearing for Pier II could not be found higher than 83 feet above datum, but that a safe foundation for Pier III would be found 20 feet higher, or at 103 feet above datum. It was also thought that the bottom of the river could be maintained at the site of the piers at about 140 feet above datum. The general rule followed in determining the size of the foundations was to make the caissons of such construction that the weight of material below the bottom of the river should not be greater than that of the sand which they displaced; and that, after deducting 400 lbs. per square foot for friction on the sides of the caissons, the weight placed on top of the latter should not produce a pressure on the foundation exceeding 2 tons to a square foot. The base required for such foundations was 92 feet long by 47 feet wide, and it was thought best to build the caissons with vertical sides below the bottom of the river.

The caisson for Pier II, with its upper works, was made 59·4 feet high, and that for Pier III, 39·6 feet high, both being alike in all respects, except in vertical dimensions. This was an error of judgment. It would have been wiser to have made them exactly alike, and each 50 feet high. Good material was found at the site of Pier II, a few feet higher than was expected, and the square foundation projects above the bed of the river. It was necessary to go deeper with Pier III than with Pier II, and the masonry of this pier begins 10 feet lower than had been desired. The caissons are illustrated in Figs. 2. They are built of southern pine timber, most of which came from the State of Mississippi. The cutting-edge is iron, of a form used by the Author at other bridges; this

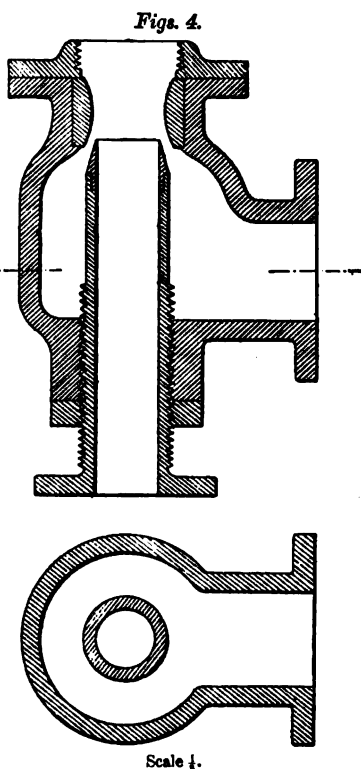
shape is preferred because it at once permits access to the actual edge when obstacles are encountered, and provides a shoulder on which the caisson can bear when sinking through sand, the edge that projects below this shoulder preventing an influx of sand from without. The V-shaped walls surrounding the working-chamber, and the entire space between the timbers for a height of 17·3 feet above the bottom, were filled with concrete after the caisson was placed in position. Above this concrete filling, for a height of 26·7 feet in Pier II, and 11·9 feet in Pier III, the interior portion only of the structure was filled with concrete, the outer parts being left empty. The upper 15·4 feet in Pier II, and the upper 10·4 feet in Pier III, are of solid timber.

The vertical side-walls are bound together by fifty-four 2-inch rods, the lower lengths of which pass through the timbers—the nuts being screwed against the under side of the shoulder of the cutting-edge and against washers on the top; in the upper part of the work, these rods are placed immediately inside the timbers. There are also twenty-four 2-inch rods similarly placed in the cross-walls, and connected with 1½-inch rods extending through the concrete. Besides these, 112 rods of the latter size extend from the roof of the caisson to the top of the concrete, near the timber intersections; and the inclined walls of the caisson are tied to the outside vertical walls with 96 rods of similar section passing across the V-shaped space. The sides of each cross-wall are tied together by thirty-six 1-inch bolts, and the timbers of the roof are tied together by three hundred and ninety 1-inch bolts. The successive courses of timber in the outer walls are fastened together with 1-inch round drift-bolts 34 inches long, spaced 5 feet apart; and as these bolts alternate in successive courses, the actual distance between them is only 30 inches. The timbers of the inclined walls of the working-chamber are fastened with drift-bolts 30 inches long spaced 3 feet apart; and the cross-walls are fastened with drift-bolts in the same manner as the outer vertical walls. The timbers of the solid filling above the concrete are fastened with thirty-four 1-inch drift-bolts spaced 8 feet apart in every stick, thus making the actual distance between the bolts 4 feet. The outside planking is secured by two 7-inch by ½-inch boat-spikes to each square foot of plank, and all other planking is fastened with two 7-inch by ¾-inch boat-spikes to each square foot. The corners are rounded and plated with ¾-inch iron. The larger caisson, for Pier II, contains 1,548 M.B.M. of timber and 424,000 lbs. of iron. That for Pier III contains 1,078 M.B.M. of timber, and 340,000 lbs. of iron.

The great depth to which the foundations were sunk, as well as the fact that a considerable amount of clay had to be penetrated, made it important to provide special machinery for passing the men up and down, and for removing the clay. Each caisson was provided with four 24-inch shafts for the removal of material, and these shafts were used to send in the concrete with which the working chamber was finally filled. Besides this there was one 36-inch shaft with a double air-lock at the bottom, of the pattern used on the piers of other works built by the Author; and one 6-foot shaft with a special air-lock at the bottom, and fitted with an elevator cage for the use of the men. Besides this, the usual provision was made of pipes for air- and water-supply, and for the removal of sand.

The device selected for the removal of the clay was what is known as a "clay hoist." It was originally designed by the Author for use on the Rulo Bridge, and had been used at Sioux City and Riparia. This arrangement is shown in detail in Figs. 3. It consists of an air-lock at the top of the shaft, behind which is placed a cylinder and piston; the speed of the piston is multiplied by two sets of sheaves, so that the stroke of the piston will lift a bucket from the bottom of the caisson to the air-lock on top; the air-lock is provided with two doors, one of which opening into the shaft below is closed by a lever

with a balance weight on the outside, and the other opening into the open air is worked by the attendant outside. The only power used is the air-pressure of the caissons. The bucket carried $6\frac{1}{2}$ cubic feet, and twelve buckets have been passed out by a single hoist in an hour. Four hoists were provided, but no more than two were ever used at a time. *Figs. 4* show the form of sand-pump used in the caisson to remove sand by a column of water. It is the



same in principle as the Eads pump used at the St. Louis Bridge, but is much simpler in construction. The special air-lock and shaft are illustrated in Figs. 5. The passenger-hoist is simply a hoisting-engine placed on the top of the working shaft, and so arranged as to be taken off with a derrick and quickly replaced when it was necessary to add a section to the shaft. The engine has large cylinders, and instead of being driven by steam, is driven by air from the caisson. The upper shaft through which the elevator-cage runs, is a cylinder 6 feet in diameter, the air-lock is 6 feet in diameter, and the shaft leading to the caisson is 4 feet in diameter. These three cylinders are side by side, the shells being connected by cast-iron door-frames carrying doors; while a fourth door opening outwards is placed at the bottom of the lower shaft; in working, the door between the two shafts was always kept closed, and the door at the bottom of the bottom shaft was always left open. It would have been possible, however, if an emergency had arisen, to use the lower section of the shaft as an air-lock by itself. When the filling of the working-chamber was completed the bottom door was permanently closed. The only power used to raise either men or material was the air of the caisson; and while this arrangement may not be as economical of power as the direct use of steam, it had the advantages of convenience and of improving the ventilation of the caissons.

It was hoped that the two foundations might be completed during the low-water season of the autumn of 1889, a hope destined to be disappointed. The first timber for the caissons was received on the 1st April, 1889, and framing was begun on the 18th of that month. The timber was received in a yard on the east side of the river, about 2,000 feet below the bridge line. A Daniels planing-machine was used to size the timber in the yard, the 12-inch timber being thus reduced to $11\frac{3}{4}$ inches; this reduction explains the slight irregularity in vertical dimensions. All other work was done by hand with ordinary carpenters' tools. The caissons were put together on launching-ways; being built directly in front of the framing-yard, and at the edge of the water. The foundation of these ways was of cypress piles driven about 25 feet into the ground. The piles were cut off and capped with 12-inch square timbers running parallel with the river, and on these were placed the ways proper; which were drift-bolted to the caps and inclined at 1 in 4 for a length of 48 feet, and at 1 in 3.43 for the remainder. The launching-shoes, which were simply transverse timbers, were placed on these ways, the cutting-edge was set up on the shoes, and the caisson was built up to a

height of 17·8 feet from the lower edge of the iron in this position.

The building of the caisson and the construction of the lower portion of the ways proceeded simultaneously. The ways were completed on the 27th of July, and two days later the caisson for Pier II was successfully launched. The caisson was fitted with a false bottom, which, however, was simply intended to prevent the lower edge from settling too rapidly in the water, and was not made tight. When the caisson was launched it drew about 12 feet. It was then kept near the bank until the condition of the river admitted of its being put in position. The caisson for Pier III was meantime constructed, and was launched on the 26th of October.

The plant for handling the work in the river comprised:—

Two steam-boats with pneumatic plant complete; one tug-boat; two anchor barges; one derrick-boat; one pile-driver boat, used also as a derrick-boat; one boat carrying a concrete-mixer; one house-boat for workmen; two barges with weaving-ways for mattresses; seven material-barges. The two steam-boats were built originally to serve as transfer boats on the Missouri. They were side-wheel boats of the type common on western rivers, each having four high-pressure boilers and two long-stroke poppet-valve engines with independent wheels. The nine barges were ordinary coal barges, such as are used on the Mississippi, 25 feet by 130 feet, and 7 feet deep; they were decked over to fit them for this work. This plant was exclusive of that used by the masonry contractor.

Before the caissons could be placed in position, the mats which were to protect the pier sites from scour had to be placed. Two barges were fitted with ways for weaving the mats, and two mooring-barges were anchored above the site of the pier, across the stream. The weaving-barges were then placed below the mooring-barges, and the material-barges were brought to the lower side of the latter. The mat was then woven on the ways, and the upper end of it was fastened to the mooring-barges and to the anchors which held them—each anchor having one line leading to one of the mooring-barges, and another line leading under the mooring-barge to the mat. As the weaving proceeded, the weaving-barges dropped down stream, so that when the mat was entirely completed, they were at the lower end, and the whole mat, 240 feet wide and 400 feet long, was floating on the water. It was then loaded with stone until it barely floated, and the upper end was submerged, but held near the surface by the lines leading from the mooring-barges. Two barges loaded with stone were then brought

to the upper end of the mat, and stone was thrown from them upon it; as it sank the barges were dropped down stream until the mat settled on the bottom. When these barges had passed over about one-half the length of the mat, the mooring-lines were cast off, and the upper end was allowed to sink to the bottom. The time required to sink the mat did not exceed ten minutes. In the case of the first mat sunk, soon after the upper end had been dropped on the bottom, the anchors dragged and the mat took a position about 120 feet further down stream than had been intended. Two mats were placed at the site of Pier II, each one containing 1,000 cords of brush and poles, 900 tons of rip-rap, and 10,000 lbs. of wire.

To facilitate handling the caisson in position, two special barges were anchored above the pier site, the lines by which the caisson was held were fastened to these barges, and a double-drum winding-engine on one of them was employed to haul the lines. The anchors used were of the pattern known as box-anchors, consisting of timber cribs, each 10 feet cube inside the timbers, filled with stone. They were built on barges, thrown overboard at the place where they were wanted, and were never recovered. Each barge was held by six steel-wire ropes $1\frac{1}{2}$ inch in diameter, leading to separate anchors, so that twelve anchors and twelve wire cables were used for one caisson. On the 23rd of September, these anchorage arrangements having been completed, the caisson for Pier II was brought into position, and was held at first by two wire ropes leading to the anchor-barges. It was also anchored laterally by a $4\frac{1}{2}$ -inch Manilla rope passing from each of two anchors situated about 500 feet distant on either side of it, through snatch-blocks, to one of the anchor-barges above. This method of anchoring and handling the caisson was devised and carried out by Mr. Noble, the Resident Engineer.

Fortunately, the current in the river was slight at this time, and no special difficulties were experienced in placing the caisson. After it was securely anchored, the concrete filling of the spaces above the working-chamber was begun, and the building of the upper works was carried on at the same time. As this proceeded, the number of anchor-lines leading from the caisson to the barges was increased until their strength was about the same as that of the lines from the barges to the anchors. On the 7th of October, the caisson grounded at 151.6 feet above datum, in 36 feet of water. Air-pressure was applied on the 10th, and fourteen days were spent in cutting away and removing the two thicknesses of mat underneath the caisson. Meanwhile the concrete filling was com-

pleted, and sinking proceeded regularly from this time, the sand being excavated by columns of water driven through sand-pumps. On the 23rd of October, the laying of masonry was begun; but, on the 30th of November all work was suspended for ten months, the water having risen to such a height that it was considered inexpedient to do more at present. The shoulders under the cutting-edge were blocked, and the foundation was abandoned until the low-water season of the following year.

The situation of Pier III was considered to be less exposed than that of Pier II, and one mat only was woven for this pier. The caisson was brought into position without serious trouble, and the concrete filling was begun on the 5th of November. The river had already begun to rise, and it continued to do so until the 25th. These three weeks formed the most critical time of the entire work. During the rise of the water, the current in the river made an angle of about ten degrees with the axis of the pier, and tended to move the caisson towards the west; on the 19th of November, the caisson was 20 feet out of place; by the aid of two tugs and of five lines leading to Pier II, it was brought within 5 feet east of its true position; four days later, all the lines leading east and one of the north-eastern lines parted, and the caisson was carried 50 feet west of its true position. Five coils of wire-rope were brought from St. Louis—350 miles—in one night; and anchors were added, until the caisson was held by eighteen wire-ropes up-stream, and five leading eastward. With these lines the caisson was brought into correct position and held there until it was completely sunk on the 10th of December, in 44 feet of water; on the following day the caisson and upper works were completed. It had been necessary to build up the sides of the caissons before putting in the solid timber, and to carry it up 4 to 6 feet above its intended height by false sides. The caisson had been saved, and no serious loss experienced. Its safety may be ascribed to: first, the mat which prevented the deepening of the bottom; and second, the strength of the anchorages. Air-pressure was applied, the mat was cut through, and sinking was conducted in the same manner as at Pier II, until the clay was reached on the 7th of February, 1890; one week later, work was suspended until the river should be in a condition more favourable to the work. Before stopping work, borings had been made below the edge of the caisson and a well sunk into the clay, which proved to be of a less substantial character than had been expected; and it became evident that the foundation must be carried lower than was originally intended.

By the middle of June the water had fallen sufficiently for work to be resumed, and on the 4th of September the foundation was completed at a depth of 18 feet lower than had been originally intended. The masonry was completed on the 23rd of January, 1891. The increased height of the pier was made entirely in the masonry, the batter being correspondingly reduced.

In September, 1890, work was resumed on Pier II; no work had been done on it for eight months, and for more than three months the entire work had been submerged. Early in the morning of the 10th of February, the steamer "Port Eads," going down the river with a tow of barges, struck the submerged pier and sank, an accident which unfortunately resulted in the loss of five lives. The cutting-edge of the caisson reached its final level on the 16th of October. An experimental well was sunk to 86.0 feet above datum, and a boring was made from the bottom of this well 10 feet lower. The whole pier, including the masonry, was finished on the 25th of April, 1891. This foundation had been sunk 6 feet less than had been expected, and the difference required for correct dimensions was obtained by a slight offset in the masonry.

The entire work on the foundations was done by men employed by the bridge company, under the direction of the Resident Engineer, the number of men worked on one foundation sometimes amounting to one hundred and sixty. When the work was begun, the caisson force was divided into three gangs, each of which worked eight hours in four-hour shifts; but as the depth increased, the working hours were shortened until, at the maximum depth, the actual working time in the caisson was reduced to two hours per day, divided into three shifts of forty minutes each, the same men going in at intervals of four hours. Good accommodation was provided for the men on the house-boat, with facilities for bathing and drying clothing. During twenty-five days the work on Pier III, and during twenty-eight days the work on Pier II, was carried on in over 100 feet of water. The actual maximum depth at which the men worked was about 108 feet.

The concrete used was composed of crushed limestone, sand, and cement. The sand was dredged from the bottom of the Mississippi river, and was of excellent quality. The cement used was manufactured near Louisville, Kentucky. In special portions of the work, German Portland cement was used. The concrete was generally made in a mechanical mixer, the capacity of which was about 20 cubic yards per hour. The mixer, together with a derrick and hoisting-engine were carried on a barge 90 feet long, 30 feet wide, and 5½ feet deep. A platform, large enough

to handle three batches of concrete, was built on the barge about 5 feet above the deck, and the mixer was placed under this platform. The cement and sand were first thoroughly mixed together, spread over the crushed rock, and shovelled whilst dry into the mixer where the water was added. The mixer discharged the concrete directly into buckets which were delivered by the derrick where required. The concrete above the working-chamber was generally gauged one barrel of cement to $7\frac{1}{2}$ cubic feet of sand and $13\frac{1}{2}$ cubic feet of crushed rock. In the lower portion of the V-shaped walls, where some leakage existed, the proportion of crushed rock was reduced nearly one-half. The concrete used to fill the working-chamber was generally mixed similarly to that used above, but the amount of crushed rock was reduced in all places difficult of access; the lowest 2 feet of concrete was made with Portland cement, and the 6 inches of filling under the shoulder of the cutting-edge, the cross walls and the flat surface of the roof were Portland cement mortar, three parts of sand to one of cement; all other parts of the filling were Louisville cement concrete.

The masonry of Pier III is shown in Figs. 6. That of Pier II is very similar, with the slight differences before mentioned. The form of pier is substantially the same as that designed by the Author for the Plattsmouth Bridge, and used subsequently on the B. C., Omaha, Rulo, Nebraska City, Sioux City, Cairo, and St. Louis Merchants' Bridges. It is a form which passes the water with little disturbance, and affords a convenient shape for the superstructure.

The cost of the two piers is given in the Tables below:—

PIER II.

—	Material.	Labour.	Total.	—
Launching-ways . . .	\$1,792·31	\$1,824·51	\$3,616·82	
Caisson	45,850·47	24,168·05	70,018·52	
Concrete above chamber .	10,528·76	3,847·05	14,375·81	
Concrete in chamber . .	3,814·66	1,310·46	5,125·12	\$93,136·27
Mattress	12,362·57	5,634·31	17,996·88	
Anchoring caisson . . .	4,619·63	2,087·55	6,707·18	
Sinking caisson	17,215·52	50,826·11	68,041·63	
Lighting pier	260·70	2,398·71	2,659·41	
Insurance	552·51	..	552·51	
Placing, sinking, &c. .	..	..	..	\$95,957·61
Total foundation . . .	..	..	..	\$189,093·88
Masonry (4,197 cubic yards)	..	..	..	\$108,669·14
Total cost	..	..	..	\$297,763·02

PIER III.

—	Material.	Labour.	Total.	—
Launching-ways . . .	\$1,885.50	\$1,788.07	\$3,673.57	
Caisson	33,117.46	17,976.84	51,094.30	
Concrete above chamber .	7,393.20	2,448.66	9,841.86	
Concrete in chamber . .	6,383.15	2,174.86	8,558.01	
				\$73,167.74
Mattress	4,543.43	2,127.85	6,671.28	
Anchoring caisson . . .	7,557.02	3,778.95	11,335.97	
Lighting pier	55.81	178.69	234.50	
Sinking caisson	19,432.91	59,534.01	78,966.92	
Insurance	394.81	..	394.81	
Protecting foundation . .	562.55	101.28	663.83	
Placing, sinking, &c. . .	..	..	..	\$98,267.81
Total foundation . . .	..	..	..	\$171,435.05
Masonry (4,870 cubic } yards) }	..	..	..	\$124,442.67
Total cost	..	..	..	\$295,877.72

The protection mat-work which still remains to be done will bring the cost of each pier up to about \$300,000. The first cost of the plant is not included in the above Tables.

Both the foundations rest on clay, Pier II being sunk 13 feet into the clay, and Pier III 21 feet. In the case of Pier III the last 9 feet were of a very sandy character, so that the foundation of the former is the better of the two. Both piers, however, rest on an entirely solid clay, free from sand. Special tests were made to determine the bearing strength of this clay. The method adopted was to cut out a large block of it, and, without giving time for it to dry or slack, to trim it so as to make a 2-inch cube protruding from a large mass of clay below; pressure was then applied to the top of the 2-inch cube. Four samples, which were taken from the chamber of Pier II, about 1 foot above the final position of the cutting-edge, were tested, with the following results:—

No. 1 broke under 423 lbs. pressure. As the weight was applied it compressed gradually. When compressed $\frac{3}{8}$ inch it gave way suddenly at the bottom, two-thirds of the top being uninjured. No. 2 broke under 343 lbs. pressure. This sample compressed $\frac{1}{4}$ inch, and then broke suddenly into several pieces. No. 3 broke under 303 lbs. pressure. It did not yield gradually, but broke suddenly along dry cracks. No. 4 broke under 343 lbs. pressure. No compression appeared to take place. The top

slipped off suddenly along a joint in the clay, and it broke in two nearly equal pieces.

Three samples tested were taken from the clay on which Pier III rests, with the following results :—

No. 1	broke under 503 lbs. pressure.
No. 2	" " 503 " "
No. 3	" " 603 " "

The first and second samples had small cracks in them, the third sample appeared to be sound.

In behaviour, the clay resembles rock rather than an ordinary clay, and is capable of withstanding much greater pressures than the piers put upon it. It is also well adapted to resist scour. It is important to compare the strength of the clay as thus tested with the actual weights put upon it. The four tests made of clay from Pier II show an average strength of 13,400 lbs. per square foot when entirely unsupported at the sides. The three samples tested from Pier III gave an average strength of 19,300 lbs. per square foot.

	Lbs. per Square Foot of Foundation.
The actual weight above the foundation of Pier II is, with the live load on the bridge.	10,410
Deduct for buoyancy below 182 feet above datum	3,722
It is expected that at least 40 feet of this foundation will be perpetually buried in the sand; and, to obtain the increased pressure on this area of foundation, deduct the weight of this sand in water	2,320
Deduct the skin-friction on 40 vertical feet of caisson, assumed to be 400 lbs. per square foot	1,029
	7,071
Actual probable pressure	8,339

It would therefore appear that, making no allowance for buoyancy, the intensity of pressure on the foundation is less than that borne by the unsupported cubes experimented upon without material compression or deformation of shape; while the actual pressure, without allowance for skin-friction, is less than one-half that borne by those cubes. Further, it must be remembered that this foundation is 40 feet below the bed of the river, and that the mats around the piers will probably prevent scour near to the latter.

The pressures for Pier III are :—

	Lbs. per Square Foot of Foundation.
Actual weight	9,934
Deduct for buoyancy below 182 feet above datum	3,075
Deduct for sand displaced.	2,320
Deduct skin-friction	1,036
	6,431
Actual probable pressure	3,503

The pressure on this foundation is a little greater than that on Pier II. As already stated, it would have been wiser to make both caissons alike and both 50 feet high, instead of 40 and 60 feet.

During the progress of the work, the river at the site of the bridge showed a gradual tendency to become deeper. This is illustrated by the seven different sections of the river bottom in Fig. 7. It will be observed that this tendency has been more marked in the western than in the eastern half of the river, and it will also be noted that the probable limit of scour is about 40 feet above the bottom of the foundation. Of course this scour may be greatly increased by local disturbances, but it is hardly conceivable that, even if greatly neglected, the bottom of the river should ever be less than 20 feet above the bottom of the foundations. Should this deep scour occur, the value of the breadth of the foundations will be evident.

The soundings show the effects of the mats around the piers. Their work has been so satisfactory that it has been thought well to reinforce them with additional mats, and to cover these with a heavy layer of stone. This will be done during the low-water season of 1892, the plan being to sink a mat 240 feet by 400 feet around each pier, and to cover these mats with from 2 to 4 feet of large rip-rap. When this is done it is believed that these piers will be as secure as any on a clay foundation.¹

The Paper is accompanied by eleven photographs and fourteen sheets of drawings. From a selection of the latter Plate 6 has been prepared.

¹ In a letter dated 3 October, 1892, the Author states that these additional mats have been duly placed.

(Paper No. 2701.)

"On the Manufacture of Modern Fixed Ammunition."

By HAROLD THOMAS ASHTON, M.Sc., Assoc. M. Inst. C.E.

FOR a long time after the invention of fire-arms, the projectile and the explosive charge comprising their ammunition were carried and loaded separately. The first step in the direction of modern fixed ammunition was made early in the seventeenth century, when the troops of Gustavus Adolphus were supplied with the charges of powder for their muskets, packed with the bullets they were designed to propel, in paper cases.

Continuous improvements in the loading and firing arrangements of fire-arms of all calibres and in their ammunition have been made since this time, the end in view throughout having been to obtain the maximum efficient speed of firing by rendering the operations of loading and discharge as simple as possible, and so allowing the principal attention to be directed to aiming the shot. This final simplicity in action, in which the ammunition plays the principal part, has only been arrived at by the most elaborate preparation of the implements and materials used; with the result that the manufacture of a modern small-arm or quick-firing cartridge is not often excelled, either in the care exercised in the selection of the material and the multiplicity of the operations performed upon it, or in accuracy of workmanship.

A complete cartridge is made up of: (1) Case; (2) Explosive charge; (3) Means of ignition; (4) Projectile.

While the bullet, charge and means of ignition are essential for the use of fire-arms, the case is a comparatively modern addition, and merely a means of uniting the other components in a convenient manner, although at the same time it is the most important element in the safety of and ease of handling the cartridge. The functions of the case before firing are to form a tightly-sealed receptacle for the explosive-charge and the means of ignition, and a holder for the bullet. In the act of firing, its duty is to form an elastic gas-check, preventing all escape of explosive gases past it; and after firing, to free itself readily from the firing-chamber.

The qualifications of a good cartridge-case are therefore: (1) That it should be as strong and rigid as may be required for transport; (2) that it should fit easily but accurately into the firing-chamber; (3) that it should retain sufficient elasticity to return approximately to its original dimensions after the pressure of the explosive gases expanding it tightly in the chamber has been released; (4) that it should be as light as is consistent with the strength required in it to resist rough usage and exposure in all climates and under all conditions; (5) that—since in all but the larger sizes of cases, to which this condition does not therefore apply, it has been found rarely possible to use a case more than once—the first cost should be as small as possible.

Attempts to fulfil these conditions have caused the paper case, which was consumed in the explosion and used in rifles carrying a permanent gas-check in their breech-action, to be replaced successively by a stronger paper case with a metallic base; by the rolled case still used for the Martini-Henry rifle, in which the thin sheet-brass forming the body is used in much the same manner as the paper that preceded it; and finally by the solid-drawn brass case, which in all sizes takes the general form shown in *Fig. 13* (the illustrations will be found on pages 310 and 311), and has been adopted universally without material variation.

The body of the case contains the explosive, and when charged is closed at the front by the projectile. The thin walls form the gas-check, which is completed by the strong base, in which is formed a central chamber for the primer. Round the base is a projecting rim or head, or an annular groove, serving as a means of extracting the empty case from the firing-chamber. The groove is more convenient for the purpose of packing, but it does not give so certain a hold for the extractor as the projecting head, which has accordingly been adopted in the British service.

Some of the larger cartridge-cases for use in quick-firing guns have been made with the base attached to the solid-drawn body by riveting or screwing, chiefly as a measure of economy in the appliances used in manufacture; and smaller cases have been similarly designed, various advantages being claimed for them; but cases of this description do not supplant to any noticeable extent the solid-drawn case above described. Until recently, only small-arms were supplied with fixed ammunition, but its use now extends to a variety of quick-firing guns, the largest of which are of about "6" calibre. Its usefulness as a means of increasing the speed of firing is, however, diminished, and finally disappears, as the weight of a cartridge increases and becomes inconveniently

heavy for dealing with by manual labour; and on this account the heaviest complete-fixed ammunition in the British service is that made for the 6-lb. quick-firing gun, the cartridges used for the 4·7-inch and 6-inch guns having only the charge and means of ignition contained in the case, which is carried and loaded separately from the projectile. In contrast with these, the smallest varieties of fixed ammunition are those made for revolver-pistols and practice with the Morris aiming-tube.

As the manufacture of all kinds of solid-drawn cases is conducted on the same lines, it will be sufficient to follow in detail the construction of the cases used in the Lee-*Metford* rifle, which may be taken as a type of the small-arm cartridge-cases adopted for the armies of the civilized world, and are made in the greatest numbers, with the greatest accuracy, and present on the whole greater difficulties in manufacture than any other variety.

PREPARATION OF MATERIAL.

The material found to be most suitable for these and all other solid-drawn cases (other than some of the smallest, which are of copper, and might be made of almost any ductile metal)—combining the strength and ductility necessary to withstand the heavy stresses to which it is subject during manufacture and in use, while being comparatively cheap—is an alloy of copper and zinc in the proportions of: copper, 65 per cent. to 70 per cent., and zinc 35 per cent. to 30 per cent. Small quantities of lead and iron are found in the best cartridge-metals, but their presence is not particularly desirable. The total amount of metals in the alloy, other than copper and zinc, should not exceed 1 per cent. Only the purest brands of copper and spelter can be used with success for this alloy, and in casting it into ingots every care has to be taken to obtain them absolutely sound and free from all impurities such as scale or other foreign matter, which, together with blow-holes, are the greatest enemies to success in its subsequent manipulation.

The ingots are cast in iron moulds, already hot from the effects of previous use, and prepared by a rub down of seal-oil and resin, or some similar varnish, to give a good surface to the casting. With the view of obtaining sounder metal, small quantities of phosphorus and aluminium have been introduced into the alloy, but experiments have failed to show that the results are beneficial or the reverse. Entirely new metal does not work as well as that cast from a mixture, of which scrap cuttings, made in

various processes in the manufacture of the case, form a large portion. Also, curiously enough, better results have followed where charges have been made from copper and spelter of certain brands and a scrap cast from different brands, than from charges in which the same brands of copper and spelter, used as a new metal also, solely compose the scrap metal of the charges; although no difference sufficient to account for the result was to be found by chemical analysis. It is also advantageous to have ample heat at command, that the charges may be melted quickly and with the smallest possible loss of zinc.

The exact dimensions of the ingots are to some extent a matter of convenience, provided that the thickness is such as to insure sufficient work being put on the metal in rolling to thoroughly solidify it. The possible importance of this may be indicated by the fact that an alloy has actually been made entirely by incorporating by pressure the two constituent metals in a fine state of division. The width of the ingot is dependent on the design of the machines used in the operations immediately subsequent to the rolling, and the length is limited by the facility in handling when the ingot is elongated in the rolls. The ingots for the manufacture of the Lee-*Metford* cartridge-case are cast about 0.75 inch thick, and 2.25 inches to 4.5 inches wide, and about 2 feet 6 inches long. After they have been trimmed they are rolled down into long narrow strips 0.14 inch thick. By the earlier or breaking-down rolls, they are reduced much more in thickness than by the later, and they are annealed at intervals.

FORMATION OF CUPS.

The metal strip thus produced is passed, after having been trimmed and examined, through machines which punch out from it circular blanks 0.875 inch diameter, and at once form them into cups in the same die (*Figs. 1 and 2*). This die has a hole passing completely through it, made in two diameters; the first and larger of these, served with an annular punch, cuts the blank which momentarily rests on the shoulder half-way through the die, and is then, by a central punch working inside the annular cutting-punch, thrust through the hole of smaller diameter, and formed into the cup. This operation, by straining the fibres of the metal over the dome and corners of the cup, serves to show any surface-defects in the metal which have previously passed unnoticed, and at each subsequent stage in the manufacture of the case, further torture of a similar nature reveals any defects existing in the metal as cast

in ingots. The amount of metal at the end of the cup forming the embryo case cannot be augmented in the course of manufacture, and is even somewhat reduced. The quantity of the metal required in the head of the finished case therefore determines the minimum thickness of the strip from which the cup is formed, and consequently the amount of work which has to be done to extend and reduce the walls to the thickness required in the finished case, in the drawing operations to which the cups are subjected after they have been annealed.

DRAWING OPERATIONS.

There are five drawing-machines used in the manufacture of the case under consideration, and by them the principal work of manufacture is done, and from their nature the "solid-drawn" case derives its name. These machines are all similar, and are only distinguished by each being fitted with the particular tools required for its share in the work. The cups, having been fed by hand into holes in a revolving table, are carried under a reciprocating punch, driven by an ordinary crank, connecting-rod and slide, which, advancing in due course, forces them one at a time through the drawing-die, which reduces their diameter and thins and extends their walls. Each case, adhering closely to the punch, upon which it is tightly compressed during its passage through the die, expands slightly when the passage is complete; while at the same time the die, relieved from strain, contracts; so that the sharp edges of the die catch on the edges of the case on the return of the punch, which is thus cleared in readiness for the next stroke. The punches and dies are copiously lubricated with soap and water to reduce friction, and to prevent the work from being scored. In each drawing-operation as much work is done upon the metal as is possible without permanently injuring it, hardening it considerably, and causing it to require thorough annealing before the next operation. All the annealings, five in number, are conducted in the same manner. The cases are heated in covered pots or muffles to a dull red heat corresponding with about 650° C., and then allowed to cool slowly. Great accuracy in temperature is not necessary to insure a satisfactory result, but care must be taken not to overheat the work, especially in the later stages, when the walls have been thinned. After annealing, the surface of the metal is cleaned by dipping it into dilute sulphuric acid. The drawing or extending operations do not succeed one another immediately in the development of the case, but are interrupted

by the first indenting operation, in which the cap chamber and head take rudimentary shape.

INDENTING AND TRIMMING.

There are two indenting operations in all, and the first is effected preferably after the first draw, and the second after the fifth draw. They are similar in manner, and, like the several draws, only differ in degree. After being indented the first time, the case appears as at *Fig. 4*, and after the second indenting as at *Fig. 9*. The result of the successive drawing operations are shown in *Figs. 3, 5, 6, 7, and 8*. For indenting, the case is supported internally by a bolster fitting it accurately, and externally by a die. A suitably shaped punch is then driven into the base of the case, displacing the metal from before it, and forcing it to flow backwards along the annular space between the punch and the supporting die. For this purpose the cases are fed by hand into the feeding-slide of automatic machines, and are delivered by carriers in front of the operating tools, which act in the order given by means of cranks, cams, or a combination of the two, and are freed from the work by a stripper. When the cases leave the drawing-machines their mouths are left with somewhat ragged edges. This is due partly to irregularity in the flow of the metal, and partly to the impossibility of keeping the punch and die absolutely in truth. As the mouth of the completed case must be of uniform substance and strength to prevent it from splitting when the cartridge of which it forms a part is finished, enough metal is provided in cutting the blank to make it, as it leaves the last drawing-machine, considerably longer than is ultimately required. The surplus length is cut off in a machine in which the cases are either fed by hand or by automatic feeding-gear on to a mandril, or into a revolving spring-chuck. A rapidly revolving circular cutter is then moved up against the case automatically, or by hand, and shears off the metal.

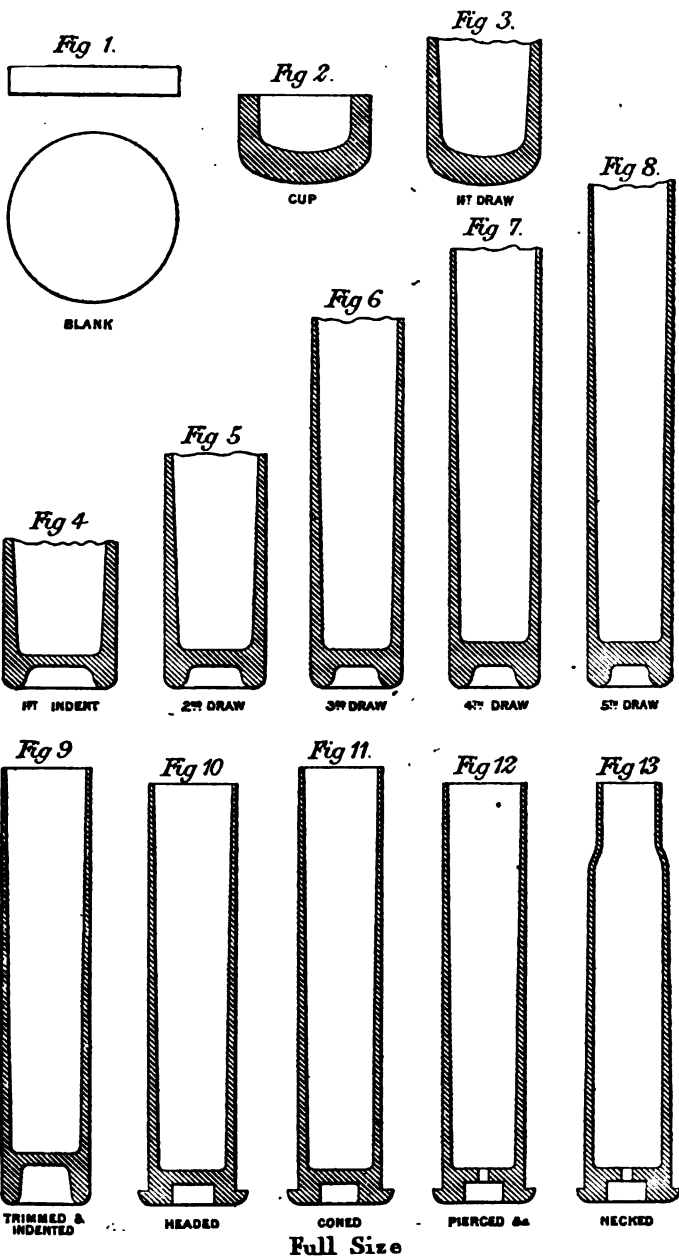
HEADING.

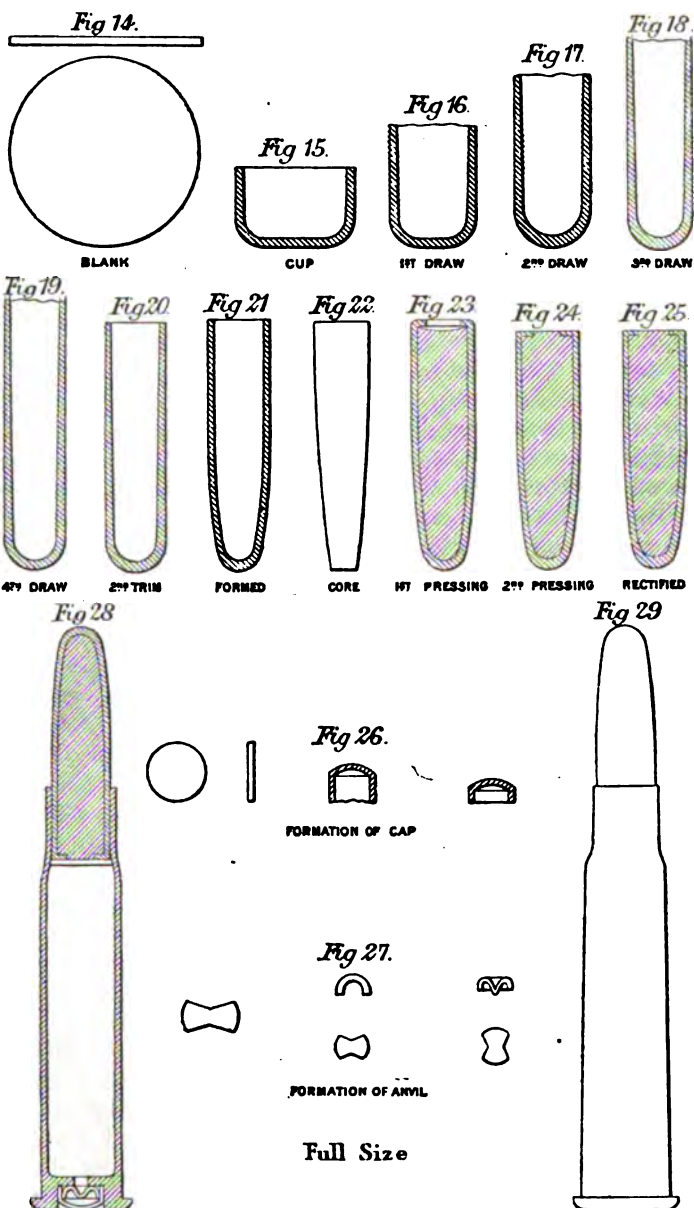
Heading the case after it has thus arrived at its full length (*Fig. 9*) is a most important operation, for on it depends the perfect freedom from escape of gas about the cap or primer, as well as the ready extraction from the chamber of the rifle after firing—two of the most important points determining the efficiency of a cartridge-case. Heading consists in up-setting the base of

the case, in which there has already been formed a deep indent, so as to form the projecting rim on its circumference and the cap-chamber at its centre, and at the same time to solidify the surrounding metal. The case after heading is shown in *Fig. 10*. The case is supported in the heading-machine internally by a bolster and externally by a cylindrical die. The die does not, however, enclose the whole length of the case as in the indenting operation, but leaves a short portion projecting, sufficient to form the rim when up-set. The heading tool, which is then impressed upon the case, consists of a dished die with a central projecting nipple of the exact size of the finished cap-chamber. Just enough taper is given to the nipple to allow it to free itself after operating and leave the case on the bolster. Great care has to be exercised in making the indent in the base of the case before heading. If made too large, the metal closes on the nipple in folds in the heading operation instead of homogeneously; and if made too small, unnecessary work is thrown upon the nipple—which it is important to avoid, as only 0·001 inch latitude is allowed in the diameter of the finished cap-chamber, so that the life of the tools is of necessity very short. The heading-machines are of various kinds. In some of the earliest the cases are placed by hand on the bolsters, which, together with the supporting dies, are carried by a revolving table under a reciprocating heading-tool driven by an ordinary crank, connecting-rod and slide. Later machines have only one die and bolster, and in them the cases are fed by hand into the slide, from which they are taken mechanically and placed opposite the operating tools, which are brought to their work in the requisite order by cams or cranks.

TAPERING.

The cases are next passed slowly over rows of gas-burners, the flames from which play only on their mouths, thus softening them for a short distance up the body while leaving the base and body hard. This is done in order that the walls of the cases may easily adapt themselves to the tapering operation which follows immediately, and to the necking or reduction in diameter of the mouth of the case which takes place after the charge is inserted. The case is tapered or coned by two machines, in each of which it is forced into a die having a suitably shaped central cavity. In the first machine most of the reduction in the diameter of the case near the mouth is effected, and in the second the die gives to the body of the case the straight taper shown in *Fig. 11*,





which is required to render insertion into and extraction from the firing-chamber easy. After the head has been turned, the distinguishing marks stamped on its base, and the fire-hole at the base of the cap-chamber pierced, the case is cleaned. The cap-chamber is then rectified, the mouth of the case re-hammered, and it is passed on to be examined and loaded, after which the final operation of necking takes place.

COMPLETING OPERATIONS.

The head is turned by a cutting-tool, which is brought against it while the case is rotating at a high speed in a tightly-fitting coned chuck, into which it has been fed by the usual combination of slides and spring-fingers, or by hand. The distinguishing marks are stamped on the base by steel dies under which the cases are brought by a revolving table. The fire-hole is pierced at two operations, the first consisting in merely making a center-mark through which the hole is punched in the second operation. The machines for each are similar, the cases being fed by hand into a revolving table which carries them opposite the tools. The cases are cleaned by dipping them into an acid solution, and, after they have been washed, placing a number of them at a time with hard sawdust in a revolving drum. The cap-chamber is rectified by the insertion of a plug made of the exact size required, serving to correct any distortion of the chamber due to the operation of tapering the case. The mouth of the case is finally reamed to give it the exact length required, and, by bevelling the edges internally, to facilitate the insertion of the bullet when the case is loaded. This is done by feeding the case into a coned bush, in which it is moved up against rapidly revolving cutters.

NECKING.

The cases are then examined and gauged, but, though the reduction of the mouth of the case to the bottle-necked shape, *Fig. 13*, is not conducted in the small case under consideration until after it has been charged, it may be most conveniently described here. In the larger cartridge-case, where the mouth is not rendered inconveniently small for the insertion of the charge by the process, the neck is formed before loading, and the case leaves the factory in its finished form; while in some types, such as the 1-inch Nordenfeldt machine-gun and the revolver

pistol ammunition, necking is not required. The method of operation is an extension of that used for coning the case. For this purpose the case is supported on its base, and a die brought down upon its mouth reduces it in diameter, and forms the straight cylindrical part and the shoulder. As under this treatment the metal does not thicken appreciably at the mouth, but obtains relief by extending slightly in length, a considerable strain is thrown on the portion of the case immediately below the shoulder, which, if too soft, bulges or buckles. Another defect occurring at this time if the metal is unequally distributed around the mouth, either as regards quality or quantity, is the formation of a crease or fold longitudinally in the straight part of the neck.

FINAL EXAMINATION.

The examination of the finished cases is most severe. No case with the smallest scar, scratch, or blemish in the shape of scaly or doubtful metal, is allowed to pass, unless it is found on a second examination to be less defective than certain defined standards. The dimensions at every portion of the case are also tried by gauges made to the upper and lower limits of size allowed. The difference between the two is so small that the gauges require considerable care to prevent their wear becoming a serious source of error in passing the work. Thus, in the diameter of the cap-chamber, the difference between the high and low gauges is only 0.001 inch, and an expert examiner will go through 7000 cases in an ordinary working day, the examination of each one wearing the gauge slightly. In the other dimensions somewhat more play is allowed, to the extent of 0.003 inch in the diameter of the body, 0.006 inch in the thickness of the head, 0.010 inch in the depth of the cap-chamber, 0.020 inch in diameter of head, and 0.015 inch in total length. All the gauging has been done till recently by hand, but machines have been in use in Germany for some time which it is stated do the work as well or better than the inspectors they replace. They have been tried in the Royal Laboratory, but have not been found entirely satisfactory. With a view to obtain uniformity in the metal of the case, the weight is also laid down as 164-5 grains.

GENERAL.

To ensure this high degree of exactitude in the product of so many operations, it is necessary that each one should do its share

of the work of manufacture with equal precision. In order that this may be done, the same standard of accuracy must be maintained in the various stamping-, drawing- and cutting-tools. As these are exposed to considerable wear in the performance of their work, it is necessary to make them of the extreme limits of size allowable and extremely hard, so that they may work for as long a time as possible before wearing to a size which causes them to produce work that would be rejected by the gauges. Also, as, apart from accidents, the only stoppages in the running of the machines are those made to allow the tools to be changed, it follows that not only the quality, but also the quantity of the work done by any manufacturing plant is dependent on the excellence attained in the tools. These may be classified as punches, dies, and cutting-tools. With the cutting-tools no great difficulties are experienced, as they can be made small in size and easy to harden, while the cartridge-metal cuts freely, and so does not wear them seriously. The punches and bolsters are required to be as hard as possible, consistent with the possession of sufficient toughness to allow them to withstand considerable shocks, and to yield slightly to work which has not left the previous operation absolutely correct. The dies for extending, coning, &c., should be somewhat harder than the punches, as they have more surface-wear to resist; they must not readily score or chip at the edges, and must not split.

In making these tools, the actual shaping presents nothing more than accurate machine-work finished to gauge, but in hardening them considerable skill is needed. Methods of hardening steel tools are very numerous, but the greater their simplicity and uniformity the better are the results obtained. Of the means specially adapted for cartridge-case manufacture the following have been found most serviceable. A small gas-furnace is convenient for heating the tools, as it is clear and the temperature can be easily watched and regulated. For dies requiring a specially hard surface, an application of potash while the die is hot gives excellent results; and for many of the tools sulphuric acid as a cooling agent gives better results than water, which is, however, more generally useful. It is not well to be continually experimenting with either the steel or the methods of hardening, nor, if the usual methods and temperatures used prove unsatisfactory, is it wise to change them at once. Sometimes steel which has turned out badly at one time has been laid aside for weeks or months, and has then, when treated apparently in precisely the same manner, worked well, owing to some changes in the condition of the steel

or of its surroundings. Changes of atmospheric temperature have a most marked effect on the hardened tools, so much so that those left in the machines from Saturday to Monday in frosty weather, or even overnight if the temperature of the factory falls considerably, rarely last beyond a very short time after the work has been resumed, the punches breaking off short, and the dies bursting and cracking. With these, as with all other hardened steel articles, an interval between the time of hardening and the time of using adds to their stability.

In manufacturing the smaller sizes of solid-drawn cartridge-cases the use of hardened steel for all tools is obligatory; but for the larger varieties, where the masses of metal in the tools are large and the stresses upon them less concentrated, cast-iron and unhardened steel may be used occasionally. Strong cast-iron has been found particularly economical for use in the coning dies for the quick-firing cases; it is cheaper than and has not the same tendency to score the cases as unhardened steel, while in hardening steel dies of the size required there is great loss owing to cracks and deformations. For large drawing-punches chilled cast-iron is used with success, and for the large drawing-dies a high carbon steel, unhardened, is found most suitable. Some other variations from the course pursued in making the smaller cases are also noticeable in the manufacture of the large cartridge-cases for quick-firing guns.

As the cases increase in size they are made in tens instead of in thousands, and are fed into the comparatively slow-running machines more often by hand and less by automatic gear. The machines employed are entirely different. The drawing-machines have heavy saddles in which the dies are placed, traversed slowly to and fro in their frames horizontally by screws or racks like planing-machine tables. The punches are fixed on both sides of a central stationary yoke, up to which the dies are moved alternately, work being done first on one side and then on the other, the traverse of the machine in each direction being utilized to effect different operations. The trimming-machines develop into specially designed lathes with chucks, into which the cases are fitted by hand. The heading-machines are large hydraulic presses, which up-set the heads of the cases under a pressure measured in hundreds of tons; or their place is taken by steam-hammers, in which a number of blows are substituted for one squeeze. Also in the large cartridge-cases the primer occupies a smaller proportion of the area of the base than is required in the smaller ones, and the hole for it is usually bored out of the solid metal.

One question enters into the construction of the machinery for the manufacture of all cases, particularly of the smaller kinds, which has not been touched upon and is of some interest. This is whether it is advisable to make machines so that the attendant merely feeds the cases into a slide or revolving table, and leaves the rest to the machine; or whether, as is possible in many of the lighter operations such as trimming, the cases should be brought to the tools entirely at the will of the operator and at a speed dependent on his skill, enabling him at his best to exceed somewhat the speed of working of an automatic machine. The non-automatic machine is simpler, and is consequently less liable to stoppages due to accidents, but the automatic machine has the advantage of running more steadily when at work. The solution of the question depends chiefly on the human element involved, and, although there are exceptions, it appears generally best to place as much reliance on the machines and as little on the attendants as possible.

Here it may be well to consider the behaviour of the case when set to do the work for which it was made. Defects which are not evident till the case fails in firing, are for the most part due to the bad quality of the metal of which it has been manufactured; but some faults are due to methods of manufacture. Of these the most serious are the complete or the partial separation of the base from the body, owing to internal folding of the metal where the walls of the case spring from the base, arising from incorrect shaping of the punches used in the later drawing operations, and escapes of gas around the primer in consequence of imperfect consolidation of the metal of the head. Splits at the mouth must either be due to bad metal or to imperfect annealing having left it hard and inelastic. On the other hand, the metal may err by being too soft, making it difficult to extract the case after firing, owing to the head and body having expanded permanently. Splits and bursts may also occur anywhere owing to defective metal. A good case may be fired several times, if ordinary gunpowder forms the charge, provided the residue from the explosion is promptly cleaned away, as otherwise the metal deteriorates. If, however, the charge is composed of any of the smokeless explosives based on the nitro-compounds, although the pressure to which the case is exposed may be lower, the intense heat accompanying the explosion appears to render the thin metal rotten and untrustworthy for future use. In the stronger quick-firing cases these evil results are not so marked, as the metal is thicker and has a greater factor of safety.

THE CHARGE.

The nature of the explosive charges used in the various cartridges, whether the mixture known as gunpowder in its original form of grain, or compressed into a pellet, or one of the many slow-burning smokeless explosives recently introduced, does not come within the scope of this Paper. It will be sufficient to point out that if the explosive is of uniform quality, all that is required to obtain the best results from it is accuracy in the weight of the charge. This is obtained in the smaller natures of ammunition by the measurement of its volume, but as it increases in quantity in the heavier ammunition each charge is weighed.

MEANS OF IGNITION.

The method of ignition, although not particularly affecting the active efficiency of the cartridge, provided that the ignition is uniformly and readily obtained, has an important bearing upon the safety of the ammunition during transit and use. A central-firing percussion cap is now always used in small-arm ammunition, and in the smaller varieties of quick-firing cartridges. It consists of a cup of brass, or of an alloy of copper with a small percentage of lead, having cylindrical sides, with a layer of detonating composition pressed into the crown. This cup is tightly fitted mouth forward into the chamber prepared for it in the base of the cartridge-case, in the centre of which, either separate and inserted with the cap or formed as part of the case by raising a conical projection in the centre of the chamber, is the anvil. When the cap is struck centrally the crown gives way and the detonating composition, crushed between the crown of the cap and the anvil, detonates and fires the charge by the flash it transmits around the anvil and through the hole or holes pierced for the purpose in the base of the cap-chamber. The pressure caused by the explosion expands the cap tightly in its chamber and prevents all escape of gas around its edges, while the cap is prevented from being blown out by the friction between its wall and that of the chamber into which it has been forced. The sensitiveness of the cap can be regulated by varying the material used for the detonating composition, or the thickness of the crown. In the larger sizes of fixed ammunition, an electrical primer is usually screwed in the base of the cartridge-case so as to be removable at pleasure. An insulated contact-piece and the body of the primer are connected by a fine wire bridge, which, when heated after the completion of

the electrical circuit fires the priming surrounding it, which in turn ignites the main charge. Escape of gas through or around the primer is prevented by packing or gas-checks.

THE PROJECTILE.

The remaining component of the cartridge to be considered is the projectile. This, the actual agent of the work to be done by the ammunition, has as many forms as there are classes of targets to be attacked, and their detailed consideration would form a wide subject of inquiry. As, however, only a relatively small quantity of shot and shell are made up in fixed ammunition, for which the great majority of projectiles are merely what may be classed as bullets, it is proposed to consider these only; and as with the cases so with the projectiles, those for the new small-bore rifle appear the most worthy of detailed consideration, as they are made in the largest quantities and present the most interesting features in manufacture. A principal object in the design of any projectile is that its powers of penetration on reaching the target should be sufficient to do the work required of it. The material and the striking-velocity of the projectile are the chief factors in this equation. It is necessary that the larger projectiles used against all varieties of defences and objects should be made of some of the hardest materials available, but this is not so with the bullets whose employment is principally against men. For these lead is universally adopted as the main element of their composition, owing to its great density and the consequent advantage obtained during its flight through the air, and to its adaptability to the most convenient methods used to impart rotation—the disadvantage attending its comparative softness being overcome by the addition of a percentage of antimony or tin, or a thin casing of some harder metal. The exact form of a projectile is comparatively unimportant, an ogival head, or that approximation to it most suitable to the material of which it is made, gives the best results, the accuracy with which the target can be hit depending chiefly on the maintenance of certain relations between the velocity, speed of rotation, and proportions of the projectile, and on their individual uniformity. This in its turn, provided regularity has been obtained in the explosive charge, is dependent upon the completeness with which the projectile follows the direction of the rifling and fills the barrel from which it is fired, and on the uniformity of the resistance therein encountered. A number of methods of arranging the

projectile to take the rifling have been used. It has been made a mechanical fit, as in the Whitworth system, or partially so, as in the studded shot used in many muzzle-loading guns, or the force of the explosion has been used to drive into the grooves of the rifling a cup, band, or coating of soft metal fixed to the projectile. In breech-loading small-arms, however, the method almost invariably used has been to make the bullet sufficiently yielding to entirely fill the bore through which it has to pass on being driven forward by the explosion of the charge in spite of its irregular shape. No great difficulty was met with for a long time in the use of this system with a lead or lead-alloy bullet, but, as the muzzle-velocities obtained from small-bore rifles were raised and the calibres were diminished, metallic fouling in the rifling at once increased in quantity, and became more objectionable. In rifles of a calibre as small as 0·4 inch, with a muzzle-velocity of upwards of 1,500 feet per second, the difficulty was met by means of copious lubrication from a bees-wax wad behind the bullet, and by covering the rear cylindrical part of the bullet with fine paper. The bullet was made of an alloy of lead and tin. But in more modern rifles in which the calibre has been reduced to about 0·3 inch, and even less, and the muzzle-velocity has been raised to 2,000 feet per second, the difficulties due to fouling have been overcome by using a compound bullet consisting of a lead core pressed into a thin envelope or casing of suitable hard alloy, which, whilst its use is free from the worst difficulties in the barrel, possesses considerably greater penetration than a bullet of the same size formed of an alloy rich in lead. This bullet is shown in *Fig. 25*. The opening through which the lead core is inserted is at the rear of the envelope, which is thicker at the nose than elsewhere, and the attachment between the two is completed by turning over the rear edges of the envelope.

Major Rubini, the inventor of the compound bullet, is reported to have successfully used a modification of it consisting of a lead-alloy bullet tipped with a steel cap to increase its penetrative power, and covered over its main diameter with specially prepared paper, but experiments in England on these lines have not given good results. Many materials, including almost all ductile alloys, and plated iron and steel, have been experimented upon, with a view to their use for the manufacture of bullet-envelopes; but nothing has been found more suitable than an alloy of copper and nickel in the proportions of about 20 per cent. nickel and 80 per cent. copper, with small quantities of manganese, iron, and silicon. This alloy is tough, hard, and

white, capable of taking a fine polish, only slightly affected by the atmosphere, and giving in rolled sheets a tensile strength of 27 tons per square inch, with an elongation of 25 per cent. in 5 inches.

PREPARATION OF ENVELOPE.

The successful manufacture of this alloy requires the greatest care, extremely small deviation from the established course producing disastrous results. There is at the outset some difficulty in obtaining supplies of nickel of uniform quality, apparently due to the variations in the amount and manner of its reduction from the nickel oxide. The nickel and copper cannot be satisfactorily cast and worked by themselves, and the small percentage of other elements present in the alloy are introduced on this account. The particular methods of their introduction are regarded by some of the manufacturers who use them successfully as trade secrets, but the best effects have been obtained in the Royal Laboratory by the addition to the copper and nickel of a small amount of silico-spiegel, originally obtained for use in steel manufacture. Other physio, including varying quantities of ferro-manganese, iron, zinc, aluminium and phosphorus, have been tried with varying results; some of the metal produced having worked well during manufacture but failed completely in the final and severest test of firing, while some of it has been entirely satisfactory.

The alloy is cast in chills in the same manner as the metal used for cartridge-cases, and is rolled down similarly, although it is not possible to do so much work upon it at each passage through the rolls without injuring it. The thickness to which the cupro-nickel strip is finally reduced is 0.04 inch, and this, after being annealed, cleaned and trimmed to a suitable width, is passed to cupping-machines similar to those used in the first operation in the case-manufacture, which at once punch out the blanks and form them up into the cups, *Fig. 15*, from which the envelopes are gradually formed. The cups having been annealed are passed to drawing-machines, which also are similar in design and action to those used for case-manufacture. These extend the envelope and thin its walls to the required extent in four operations which are accompanied by two trimming operations, in which the ragged edge at the mouth of the partially formed envelope is cut off, before and after it is drawn for the fourth time. It is not found necessary to anneal the cupro-nickel after every

drawing operation, as is the case in dealing with the brass used for the cartridge-cases. Indeed, it is the practice of some manufacturers not to anneal the cupro-nickel after any operation subsequent to the formation of the cup. In the Royal Laboratory, however, the metal is found to give the best results if annealed after the fourth drawing operation.

In order to make the envelope with the rounded nose required, the drawing-punches are approximate in shape to the final internal form. They cannot be made exactly of this form without being liable to punch out the front of the cups when descending upon them to force them through the drawing-dies. Consequently the envelopes leave the drawing and trimming operations as hollow cylinders open at one end and closed by a dome at the other end, the interior cavity being slightly tapered, as shown in *Fig. 20*. In order to bring them to their finished proportions they are passed to the point-forming machines, in which a punch, made exactly of the internal size of the finished envelope, presses them home into a die the exact size of the finished bullet. This tries the metal severely, for, although if good it receives no injury, weak or brittle metal gives way round the punch, which passes through the front of the would-be envelope and at once destroys it. After being formed, the envelope is completed by having its mouth reamed, and being trimmed to length.

PREPARATION OF LEAD CORES.

The lead cores now inserted by hand into the envelopes are made of an alloy of lead with 2 per cent. of antimony. This alloy is squirted into a rod by hydraulic pressure, for which purpose it is cast into a cylindrical chamber in the head of a hydraulic press, which is raised immediately the metal has set. Directly above the cylindrical cavity, and entering it when the ram is raised, is a fixed piston in whose centre is placed a hardened steel die, with a central hole through which the semi-plastic metal is squirted as the ram continues to rise. It is curious that the die through which the lead is forced continues to grow smaller for some time after it is first put in, instead of wearing larger as would naturally be expected. This is due to the high temperature of the lead taking the temper out of the steel, and causing the die to shrink at a greater rate than is compensated for by the wear due to the passage of the lead. To make the cores, the lead rod is passed to machines which cut it into short lengths, which are formed to the required shape by pressure in a die or mould.

ASSEMBLING, ETC.

After the cores have been placed in the envelopes by hand they are pressed home so as to fill them completely. The envelope is held for the time in a die of the size of the finished bullet, and the tool that presses in the core turns in the rear edges of the envelope slightly, in readiness for the next operation, which consists in pressing these edges firmly down on the core and consolidating the whole bullet. After this, a cannellure or groove to contain lubricant is formed near its base, by rolling it between a suitably shaped revolving disk and a fixed block. Then, after the bullet has been finally rectified for diameter by passing it through a die to give it the exact diameter required in the cylindrical portion which is to fill the rifling, it is complete and ready for inspection.

EXAMINATION.

This is carried out with the same rigour as is observed with the cartridge-case. All bullets showing indications of defective or overstrained metal in the envelopes are at once rejected. Two-thousandths of an inch are allowed between the high and low diameters of the bullets, but more latitude, viz., 0.032 inch, is allowed in its length. Large numbers of bullets are fired into water or sawdust, and are afterwards examined to ascertain whether the envelope has held well together, and neither cracked along the marks made by the rifling nor been torn away at the rear. The weight is an important point, and is allowed to vary between 215 ± 3 grains. Of this the envelope weighs from 57 to 60 grains.

The machines used in the manufacture of the compound bullet are all made on lines similar to those used for making the cartridge-cases; in all, the envelopes or bullets are fed into tables or slides by hand, and delivered to the operating tools by mechanical means. Also in the manufacture of the envelope, in which the chief difficulties in making the compound bullet lie, success depends as much on the quality of the tools used as in the manufacture of the solid-drawn case, and the qualifications required in them are the same. The cupro-nickel is, however, both harder and stronger than the brass, and consequently wears the tools more rapidly, and causes them to scratch more easily.

As with the case so with the projectiles, more latitude is given in respect of weight, dimensions, quality of material and defects

in manufacture, in the larger sizes of small-arm or quick-firing ammunition; but the inspection of all varieties is extremely stringent.

ASSEMBLING THE CARTRIDGE.

In assembling the several components to form the complete cartridge, the object chiefly sought, after the production of perfectly sound ammunition, is safety while the work is being performed. This is attained by a system of carefully-inspected danger-buildings in which numerous precautions are taken, and from which all men and materials not actually required are excluded.

The operations here performed being similar for all kinds of ammunition, need only be particularly referred to as applied to the small-arm class, the manufacture of bullets and cases for which has already been described. First, the cap, after having primed, is inserted in the case, and firmly pressed home into the chamber prepared for it. Then after the insertion of the charge the case is bottle-necked in the manner described. The internal diameter of the neck is made such as to just admit the bullet, the base of which has previously been coated over with bees-wax, and is inserted in the case over wads—the bees-wax doing double duty as lubricant for the bullet and water-tight packing between the latter and the case. The neck of the case is then finally pinched on to the bullet and indented for cordite and cannellure, when the cartridge is complete. The examination and gauging which follows is chiefly designed for the detection of faults due to the manner of assembling, but also acts as a check on the previous examinations of the components of the cartridge. Every cartridge is tried in a socket-gauge, smaller than the chamber in which it is intended that it should be fired, and most of the external dimensions of the cartridge are also gauged separately. The bundles of cartridges, as made up for service, are all weighed to make certain that no cartridge has found its way through the factories with any hidden part missing, such as the whole or a portion of the charge, or core of the bullet. Proofs are fired for velocity and accuracy, any defects developed in bullets or cases being noticed at the same time, while separate firing-proofs specially for the detection of such defects may also be taken.

The accuracy of the shooting obtained from any ammunition, considered apart from the influence of the rifle used, depends on the extent to which uniformity is obtained in the components of

the cartridges, and in their arrangement on assembling, a principal factor being the hold which the case has upon the bullet; for, although insignificant in comparison with the enormous pressure finally developed by the exploded charge, the pressure required to start the bullet from the case has a considerable effect on the burning of the charge, particularly if it be made of one of the new smokeless explosives.

The tightness with which the bullet fits the mouth of the case has also considerable effect upon the stability of the cartridges under the rough usage to which they may be subsequently subjected. For, although carefully packed, their treatment in transit by sea and land is sufficiently rough to make itself severely felt. In use also they may have to bear considerable violence, for it can easily be imagined that the speed with which 500 or 600 cartridges per minute travel backwards from the feeding-belt, forwards into the firing-chamber, and with which the empty cases are extracted, in the Maxim automatic gun, is a severe trial both for the complete cartridge and for the fired case. The safety obtained by the use of the solid-drawn case enclosing the charge is remarkable; for experiments have shown that it is impossible to explode any number of such cartridges at once, either by firing one of their number or by firing into the mass. It is for such important qualities that fixed ammunition having the solid-drawn case has been preferred to all other varieties, and, indeed, has, owing to the extended use of machine- and quick-firing guns, become indispensable.

With regard to possible future developments, it may be interesting to note that ammunition has been made in which a portion of the duties usually assigned to the case is performed by the charge; which, in the form of a durable stick or tube of smokeless explosive, is attached at one end to the bullet, and at the other end to the rudiments of a solid-drawn cartridge-case, consisting of a short gas-check with a strong base containing the detonator. Such cartridges have not as yet, however, come into practical use, and cartridges of the type shown in *Figs. 28 and 29* remain for the present the principal form assumed by modern fixed ammunition.

The Paper is illustrated by a drawing from which the *Figs.* in the text have been prepared.

APPENDIX.

ON THE MANUFACTURE OF MODERN FIXED AMMUNITION.

List of operations in consecutive order in the manufacture of cartridges for the Lee-Metford rifle, as performed in the Royal Laboratory, Woolwich:—

MANUFACTURE OF CASE.

Cast cartridge-metal into ingots 0·75 inch thick.	Anneal.
Roll ingots into strips 0·14 inch thick, annealing them three times at intervals.	Fifth drawing operation.
Trim and examine brass strip.	Trim mouth.
Punch out blank disk from strip and form cap in the same machine.	Second indenting " "
Anneal cup.	Heading.
First drawing operation.	Semi-anneal (soften mouth).
First indenting " "	First operation tapering.
Anneal.	Second " "
Second drawing " "	Turn head.
Anneal.	Stamp distinguishing marks on base.
Third drawing " "	First operation piercing fire-hole.
Anneal.	Second " " "
Fourth drawing " "	Clean.
	Rectify cap-chamber.
	Reamer mouth.
	Examine and gauge.

MANUFACTURE OF BULLET.

Envelope.	Core.
Cast cupro-nickel ingots.	Cast and squirt the lead alloy into rod.
Roll to strip 0·04 inch thick.	Cut off and form the cores from the rod (in same machine).
Annealing at intervals.	
Trim and examine strip.	
Punch out blank disk and form cup (in one machine).	
Anneal.	
First drawing operation.	
Second " "	
Third " "	
Trim to length.	
Fourth drawing operation.	
Trim to length.	
Form point of envelope.	

INSERTION OF CORE IN ENVELOPE.

- 1st operation—pressing core home and turning over envelope.
 2nd " " " " "
 Cannellure bullet.

Rectify for diameter.
Examine and gauge bullets.
Lubricate.

MANUFACTURE OF PRIMER.

Cap.

Cast and roll strip for cap.
Punch out blank disk and form cap (in same machine).
Trim cap to length.
Prime cap with detonating composition.

Anvil.

Cast and roll brass strip.
Punch out blank.
Form up blank—first operation.
" " second "
Insert anvil in cap, and complete primer, examine and gauge.

ASSEMBLING.

Press cap into cap-chamber.
Load case with explosive charge.
Insert glazed-board disk over charge.
Neck the case ready to receive bullet.
Insert bullet in case.
Choke neck of case on bullet.
Examine complete cartridge.

ANALYSIS OF CARTRIDGE-METAL.

Copper, 70 to 65 per cent. ; zinc, 30 to 35 per cent. ; iron, 0·17 per cent.
and lead, 0·17 per cent. about—traces of arsenic, &c.

AVERAGE-ANALYSIS OF CUPRO-NICKEL ENVELOPES.

Nickel (including traces of cobalt), 19·7 per cent. ; copper, 80 per cent. ;
iron, 0·75 per cent. ; manganese, 0·1 per cent. ; silicon, 0·02 per cent.
with traces of arsenic.

(*Paper No. 2746.*)

"Irrigation Reports¹ of the U.S. Geological Survey and Hydrography of the Arid Region," (49 Plates, 7 Figs.).

By F. H. NEWELL.

Eleventh Census of the U.S., 1890. Washington 1892.

Abstracted by OWEN CHARLES DALHOUSIE ROSS, M. Inst. C.E.

OVER nearly one-half of the continent of North America, lying in a general north and south direction, west of the hundredth meridian, the rainfall is insufficient for the needs of man. It is a consequence of its topographical features, of the elevation and distribution of the mountain masses, that this arid land stretches in a general longitudinal direction instead of crossing the continent from west to east. In this vast area, which contains great deposits of mineral wealth and embraces several hundred million acres of agricultural land as rich as any on the globe, the hydrographic investigations of the Geological Survey chiefly consist of measurements of the water flowing in the rivers, or stored in the lakes, with the view of adding to the irrigated area (1) by a more intelligent utilization of the available supply, and (2) by increasing the quantity of water which might be drawn from those sources.

At present the area cultivated by irrigation (3,564,416 acres in 1889) is often so scantily supplied that each year the crops upon thousands of acres are injured, or lost, for lack of water at critical times. The common method of irrigating forage crops and the small grains is by flooding the land to a depth of 2 or 3 inches, or more; for other crops it is allowed to run along the furrows until the intermediate ground is saturated, and for fruit trees, or vineyards, small trenches are dug, or ploughed, from the distributing ditch to each tree, but there is no doubt that a larger area might be successfully cultivated by employing the present available supply with greater economy. One second-foot of water, or 1 cubic foot of water flowing 1 foot per second throughout the irrigation season, should suffice with care for the irrigation of

¹ The originals are in the Library Inst. C.E.

100 acres, and in California and Arizona it is even made to cover 120 acres, but, when wastefully used, it often only suffices for from 40 to 50 acres, or even less.

In many parts of the arid region there are fertile plains suitable for arable land so vast that by no possibility can they ever be brought under irrigation, but there are also very extensive areas which can be reached by canals, some of which are in course of construction or projected; and, moreover, the river floods bring down at irregular intervals great quantities of water which is allowed to run to waste. It is only a question of time, it may be five years or fifty, when storage dams will be built to hold back this flood-water and employ it in irrigation.

Before any steps can be taken towards the construction of such dams, ample and accurate information must, however, be collected on which to base conclusive estimates as to the success of the enterprise, and during the last few years numerous observations have been carefully collected respecting the various drainage basins. In a series of Tables and Diagrams which accompany the text, the daily discharge at a very large number of gauge-stations is tabulated, and everywhere testifies to an extraordinary variation in the flow of water. The following examples of minimum and maximum discharges are amongst the most remarkable:—

Name of State.	Name of River.	Minimum Discharge.	Maximum Discharge.	Period of Observations.
		Second-Feet.	Second-Feet.	
Idaho .	Weiser River . . .	80	11,220	{ Year ended Feb. 28, 1891.
Oregon .	Owyhee	170	11,230	{ Year ended Mar. 31, 1891.
Montana .	Yellowstone. . .	285	11,915	{ Year ended Dec. 31, 1890.
Montana .	Missouri River . .	1,742	16,355	{ Year ended Dec. 31, 1891.
Texas .	Rio Grande . . .	45	16,620	Month of May, 1891.
California	Tuolumne	130	22,900	{ Six years, Nov. 1, 1878, to Oct. 31, 1884.
Idaho .	{ Snake River (Idaho Falls) }	2,286	50,450	{ Year ended June 30, 1890.
California	San Joaquin . . .	260	59,800	{ Six years, Nov. 1, 1878, to Oct. 31, 1884.
California	Sacramento . . .	5,050	160,000	{ Six years, Nov. 1, 1878, to Oct. 31, 1884.
Arizona .	{ Salt River (Arizona Dam) }	397	300,000	{ Year ended Feb. 28, 1891.

Bearing in mind that each second-foot of water is calculated to irrigate 100 acres, the figures in the fourth column, which indicate

flood-waters that are to a great extent now wasted, serve to illustrate the magnitude of the results attainable by their successful storage; but the building of the requisite works must necessarily proceed slowly, and the experience of the past few years shows that large sums will be required in order to insure solid and permanent construction. The mean variation between the maximum and minimum discharge at one hundred and thirty gauging-stations appears to be about 27 to 1, but on many rivers the flood-discharge does not exceed from 5 to 10 or 12 times the average of the whole year.

The principal rivers in the arid region, and the nature of the country through which they flow; the extent of the basins from which they derive their supply of water; the amount of discharge at various seasons; the area under cultivation and under irrigation, with many other particulars, are described very fully by the Author. The drainage area of the Rio Grande above its junction with the Pecos river is stated to be 145,200 square miles in extent, and that of the Colorado river 225,049 square miles. Of the 124,808 farms, comprising 36,899,000 acres, enumerated in the arid region in June, 1890, 42·13 per cent. contained land, on some of which crops were raised by irrigation in 1889, and the following Table shows the area of irrigated land, as well as the value of the products corresponding to each State or Territory.

States and Territories.	Number of Acres Irrigated in 1889.			Average Size of Irrigated Farms.	Value of Products in 1889.		
	Forage Crops.	Cereals.	Total.		Average Value per Acre.	Total Value.	
				Acres.	£	s.	d.
Arizona .	43,321	22,500	65,821	61	2	18	0
California .	474,233	530,000	1,004,233	73	3	19	2
Colorado .	625,735	265,000	890,735	92	2	14	8
Idaho .	154,005	63,000	217,005	50	2	13	11
Montano .	275,582	75,000	350,582	95	2	14	0
Nevada .	209,403	15,000	224,403	192	2	13	10
New Mexico	33,745	58,000	91,745	30	2	13	4
Oregon .	124,544	53,400	177,944	56	2	17	11
Utah .	148,473	115,000	263,473	27	3	15	2
Washington	28,299	20,500	48,799	47	3	11	2
Wyoming .	210,676	19,000	229,676	119	1	14	4
Total .	2,328,016	1,236,400	3,564,416	67	3	2	0
							11,053,540

Of the irrigated area 50·36 per cent. was in farms under 160 acres ($\frac{1}{4}$ square mile) and 49·64 per cent. was in farms of 160 acres and upwards.

The preceding statistics concerning the acreage and value of land and products have been taken from the enumerators' returns for each agricultural holding, while the following facts have been obtained by direct correspondence with farmers by means of special schedules addressed to each irrigator. These schedules contained questions intended to cover facts concerning the location of irrigated land, the character of the water-supply, the cost of irrigation, methods of using the water, necessity of irrigation, the use of artesian wells and pumps; also the location of canals or irrigating ditches, size and cost, methods of distributing the water, &c. In all about thirty thousand replies have been received, and from these, after proper tabulation, certain averages have been drawn, the principal of which are as follows:—

(1) The average first cost of bringing water to the land has been £1 13s. per acre, this average being derived from the statements of all persons who have constructed ditches or have purchased water-rights from canal companies, or others. The highest average is in the case of California, where the most thorough and expensive systems for saving and distributing water have been constructed; the lowest in Wyoming, where enormous areas have been covered with water by means of ditches quickly and cheaply constructed by means of plough and scraper, costing little more than one-fourth what has been spent in California.

(2) The average value per acre of these water-rights, wherever they can be considered independently of the value of the land, is £5 6s. 4d., but in many localities the water-right cannot be taken from the land without depriving the latter of its entire value, for without a water-supply the land is worthless. Taking, however, those cases in which water-rights are transferable and are sold, or treated like other pieces of property, the difference between £1 13s. and £5 6s. 4d., or £3 13s. 4d., may be regarded as the average profit per acre to the creator of the water-right.

(3) The average annual cost of repairing and keeping ditches in good order, or otherwise maintaining the water-right, is 4s. 6d. per acre.

(4) The cost of bringing the land under cultivation beyond the expense for water, but including fencing, &c., has varied considerably. In California, owing to the greater amount of labour spent upon it, the average reaches £3 12s. 10d., but the cost throughout the arid region has averaged £2 10s. 6d. per acre. Applying these averages—which are given in detail for each state and territory—with proper modifications, to the total acreages of those States, it would appear that the approximate first cost of irrigation in the

entire region has been £6,168,960, and, the total water-rights in 1890 being valued at £19,669,160, the increase in value or profit on the expenditure incurred in works of irrigation appears to have amounted to £13,500,200, or 218 per cent. The proportion in which the cost and profits of the irrigation in the arid region apply to each State is shown in the following Table:—

State or Territory.	First Cost of Irrigation.	Value of Water-rights in 1890.	Increase or Profit.
	£	£.	£.
1. California	2,709,375	8,217,910	5,508,535
2. Colorado	1,326,875	5,281,250	3,954,375
3. Utah	579,166	1,473,333	894,167
4. Montana	338,125	1,098,542	760,417
5. Wyoming	266,875	791,875	525,000
6. Nevada	260,625	773,750	513,125
7. Idaho	214,375	595,833	381,458
8. Oregon	172,084	573,958	401,874
9. New Mexico	106,666	349,792	243,126
10. Arizona	96,875	172,500	75,625
11. Washington	41,044	133,750	92,706
12. Sub-humid region . .	56,875	206,667	149,792
Total	6,168,960	19,669,160	13,500,200

The results shown in the above Table apply to irrigation constructions or rights considered apart from the land. Adding to the first cost of the land which was irrigated in the census year that of its cultivation, and of the building of fences and other necessary operations, as well as the cost of bringing water to it, the Author arrives at an approximate estimate of the expenditure upon the total irrigated land amounting to £16,143,750, whereas its value on the 1st of June, 1890, as derived from the statements of a majority of the owners, was estimated at £61,843,750, thus showing an increase of £45,700,000, or 283·08 per cent.

The average cost of irrigating canals under 5 feet in width, including headworks, flumes, &c., was £100 per mile; of those from 5 to 10 feet in width, £339 per mile; and of those exceeding 10 feet in width, £1,167 per mile.

A separate Census Bulletin, dated the 17th of May, 1892, deals with the subject of artesian wells for irrigation. The total number at the time when the census was taken (June 1890) on

farms in the arid and sub-humid regions was 8,097, representing an estimated aggregate cost of £414,283. Complete statistics concerning the depth, cost, discharge and other features of 2,971 of these wells have been obtained from the owners, from which it results that the average depth per well was 210·41 feet, the average cost per well £51 3s. 4d., the total discharge of water per minute 440,719·71 gallons, or 54·43 gallons per well per minute, the average area irrigated per well 13·21 acres, and the average cost of water per acre irrigated £3 17s. 4d. More than half of these wells are in California, where 38,378 acres of agricultural land were irrigated by artesian water. The average cost of water per acre by ordinary means of irrigation was £1 14s. 0d., which is less than half of the cost by artesian wells; and it should moreover be borne in mind that a great many attempts, aggregating perhaps thousands, have been made to obtain flowing water, which have been unsuccessful.

Artesian wells result usually from the drilling of porous strata filled with water, which is held from escaping by impervious rocks both above and below, the hydrostatic pressure on this water due to the inclination of the bed being sufficient to force it to the surface, but for more exact definition the Author refers to a Paper entitled "The Requisite and Qualifying Conditions of Artesian Wells," by T. C. Chamberlain, in the fifth Annual Report of the U.S. Geological Survey, as being, without doubt, the most comprehensive description of this subject. Most of the wells are drilled into nearly level unconsolidated rocks of late pliocene or pleistocene epochs, but the deeper wells in the States of Dakota and Texas, which are often 1,000 feet or more in depth, obtain their supply from the base of the cretaceous formation, and these are the largest and probably the most permanent artesian areas of the country. The greater part of the water which has been raised in this way is used upon small gardens in the vicinity of houses, and for fruit and shade trees, for watering lawns, and for raising grass either for pasturage or hay; for the ordinary field crops it has been employed only to a small extent.

A Table is given showing the number of artesian wells in each county of each State, together with the depth of the deeper and shallower wells and the average depth, and the cost and discharge in gallons per minute of those wells for which statistics were obtained from the owners.

(Paper No. 2742.)

“Experiments on the Measurement of Water over Weirs.”

By VICTOR AUGUSTE ERNEST DWELSHAUVERS DERY,

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THE Author has adopted a title that Messrs. Donkin and Salter gave to a paper, published by the Institution, in 1885,¹ because his investigations have the same object, namely, to determine the coefficients of discharge of a rectangular weir, 2·9528 inches in width (75 mm.), formed in a sheet of copper bevelled throughout the perimeter, and over which was passed the whole of the circulating-water of a condenser for the purpose of gauging it. This condenser belongs to the mechanical laboratory of the School of Mines of Liège. The weight of circulating water is one of the experimental data necessary for applying Hirn's method.

The formula employed to calculate the flow, Q cubic metres per hour, over a weir of width L metres, the height of water over the weir being h metres, is, as is well known :

$$Q = 3600 \times \frac{2}{3} L \sqrt{2g} \times h^{\frac{3}{2}} \times C;$$

which reduces to—

$$Q = C \times 797 \cdot 22 h^{\frac{3}{2}} \text{ when } L = 0 \cdot 075;$$

$$\left[\text{or } Q = C \times 118 \cdot 354 h^{\frac{3}{2}} \text{ when } L = 2 \cdot 9528 \text{ inches, and } h \text{ is in inches and } Q \text{ in lbs. per minute.} \right]$$

This coefficient C varies with the depth of water h , as was shown by Messrs. Donkin and Salter, and it can only be determined by experiment. The object with which the experiments were undertaken by the Author, was to investigate the law of variation of this quantity, and to deduce from it the expenditure of water per hour, corresponding with the different values of h , increasing by increments of 1 millimetre from 10 to 110 millimetres. The results of these experiments are given in the Appendix, and it is thought that these results will have a certain interest for those engaged in the experimental study of the steam-engine.

¹ Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 377.

The same general method was employed as that of Messrs. Donkin and Salter, with a few modifications of detail. The water to be gauged is delivered in a tank 3 metres long by 1 metre wide and 1.20 metre in depth. The tank is divided into two equal compartments by a water-tight partition, in which the weir is arranged, and all necessary precautions are taken to ensure that the sill shall be accurately horizontal. The water is received in the first compartment, and brought to rest by a series of baffles, so that it spreads out above the weir in an apparently motionless sheet. It passes over the weir into the second compartment, where there is a graduated tube by which the level is read. The graduation was made by weighing the water with the utmost possible care. At the end of the second compartment is a valve for discharging the water.

During the operations in question, after the desired depth h was obtained, the discharge-valve was closed, so that the level of the water rose in the compartment, and could be observed on the tube graduated in millimetres. An observer marked the passage of the level of the water through zero, and then through 10, 20, etc., centimetres up to 70. The Author observed the times of these passages by means of a stop-watch clearly indicating quarters of a second.¹ The graduation of the tank showed that between the levels 0 and 70 there was 1.057327 cubic metre of water introduced. One-seventh part of this quantity, or 0.1510467 cubic metre, was the constant by means of which the period of flow was calculated. The time required for this same quantity of water to pass over the weir was observed seven times in succession, with a constant depth h , on the weir. The graduations at every 10 centimetres served to check the progress of the experiment. The Author then plotted the results on a diagram, *Fig. 1*, taking as abscissæ the depths of water h , and as ordinates the times t , for twenty-six reliable experiments, in which h varied from 10.9 millimetres (0.428 inch) to 102.2 millimetres (4.016 inches).

One of the greatest difficulties was to keep the depth h constant during the whole of one experiment. Sometimes numerous trials were necessary to arrive at this condition. The water was supplied from a large reservoir, having a capacity of at least 27 cubic metres (953 cubic feet), its bottom measuring 7 square metres (75 square feet), which was placed on a foundation 2 metres (6.5 feet) in height. It passed through the condenser to arrive at the

¹ This stop-watch was a Telford Premium from the Inst. C.E.

measuring-tank, and the flow was controlled by a tap. The large reservoir was fed by the town water-main, a branch from which also had a tap, by means of which the level in the large reservoir was maintained constant, being marked by a floating indicator. The measuring-tank was furnished with the floater described by Messrs. Donkin and Salter, and with a magnifying glass one could read it with sufficient accuracy to the tenth part of a millimetre ($\frac{1}{250}$ inch). These readings were taken by the Author personally. When the experiment occupied much time, the pressure from the town sometimes changed and embarrassed the working of the regulating tap; the depth, h , did not remain entirely constant; several experiments have been discarded on this account. During the whole duration of the twenty-six successful experiments, the level of water in the measuring tank was maintained steady within $\frac{1}{250}$ of a millimetre. The zero of the scale of the floater was checked every day by the method of Messrs. Donkin and Salter.

The following Table gives the results as obtained from the twenty-six successful trials, that is to say, the depth h in millimetres and the time t in seconds, occupied in delivering 0.1510467 cubic metre of water, which represents $\frac{1}{4}$ part of the total volume of water delivered in one experiment:—

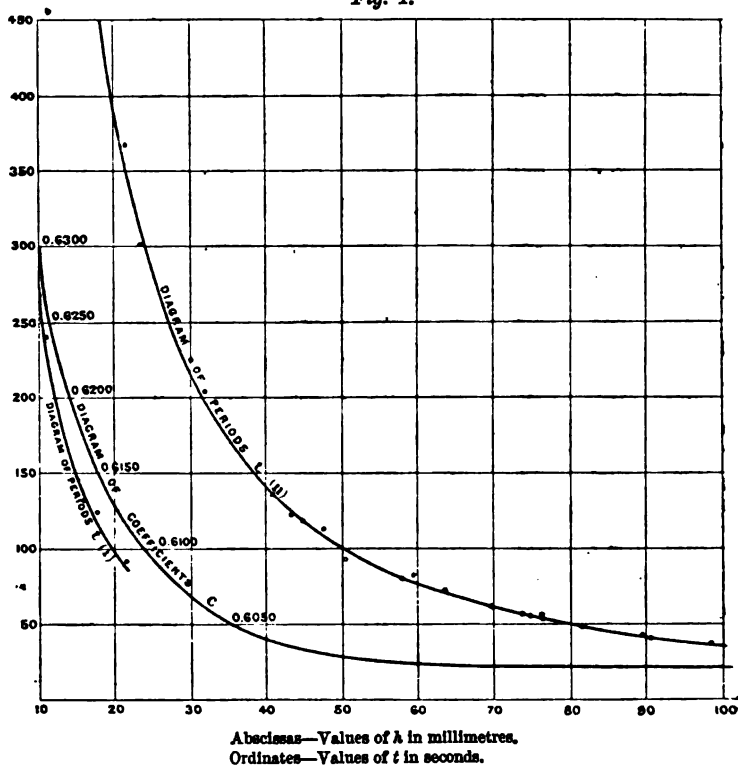
h Milli- metres.	t Seconds.	h Milli- metres.	t Seconds.	h Milli- metres.	t Seconds.	h Milli- metres.	t Seconds.
10.9	961.0	41.0	136.03	63.5	71.86	89.5	43.43
16.0	528.0	43.5	123.14	69.7	61.50	90.5	41.71
17.6	498.8	44.8	119.14	73.7	56.71	98.5	37.00
21.5	367.8	47.4	112.93	74.5	55.71	101.0	35.57
23.6	301.3	50.3	92.80	76.2	55.64	102.2	35.25
30.0	225.8	58.0	81.29	76.3	54.47	..	..
31.8	203.8	59.5	82.00	81.5	49.00	..	..

On the diagram, *Fig. 1*, these results are represented by the centres of the small circles; the co-ordinates of these points were on the following scales in the original drawing:—

The lengths along the axis of abscissæ represented the depth h on the scale of 5 to 1, the origin being marked 10 millimetres, the experiments not having been carried further. Between the abscissæ, $h = 20$ and $h = 110$, the ordinates representing the times were to the scale of 1 millimetre per second. But the sheet of paper being only 450 millimetres in length it was necessary to employ another scale between $h = 10$ and $h = 20$, viz., $\frac{1}{4}$ millimetre per second. The diagram of the times t was thus divided into two parts, marked (I) and (II), see *Fig.*

Having obtained the points which show the actual results, it was necessary to draw in a rectifying curve, and deduce from it the different values of the coefficient C , and to represent them also by a diagram with the same independent variable h . This operation was delicate and difficult, because the smallest deviations of the curve of the times t gave rise to inadmissible sinuosities in that of the coefficient C , which was traced to a very large scale, on

Fig. 1.



which 1 millimetre represented $\frac{1}{10,000}$; the dimensions of the sheet of paper permitted this, because the value of C was comprised within very narrow limits, namely, 0.60 and 0.63, and thus 30 centimetres of height were sufficient.

After many trials the Author arrived at a very clear trace on the diagrams of the coefficient C , as it is shown in the Fig., and it is from this curve that he has then calculated a series of the values

of the times t corresponding to different values of depth h , in order to obtain the diagram of the times t and to compare it with the series of points representing the actual experimental results.

It may be remarked that this curve passes almost exactly through eight of the experimental points lying between $h = 40$ and $h = 95$, and that it does not depart considerably from any of the eighteen other points.

In order to pass from a given curve of C to the corresponding curve of t , or inversely, the process adopted results from the equation expressing that the experimental flow per hour is equal to C times the theoretical flow :—

$$0.1510467 \cdot \frac{3,600}{t} = Q = C \times 797.22 h^{\frac{3}{2}}.$$

The values of h are given. Those of t are shown on the diagram of times. Those of the product $797.22 h^{\frac{3}{2}}$, are calculated. It follows that a simple division will give the quotient C . Or inversely, the values of C will be found on the given diagram of this coefficient, and from them may be deduced, first the value of Q and then that of t by means of the preceding equation.

The Author thinks it useful to give in an Appendix the results that he has obtained; the first column contains the different values of h , between 10 and 110 millimetres, proceeding by differences of 1 millimetre. The second gives the calculated values of the theoretical flow

$$Q_m = 797.22 h^{\frac{3}{2}}.$$

In the third are the coefficients C taken from the diagram; in the fourth the actual flow calculated by the formula

$$Q = C \times Q_m.$$

Finally, between the values of $h = 70$ and $h = 102$ millimetres, the coefficient C was found so nearly constant that it has been supposed constant and equal to 0.60220, even up to 110 millimetres.

The Paper is accompanied by a diagram from which the *Fig.* in the text has been prepared.

APPENDIX.

TABLE OF RESULTS.

λ in Inches.	λ in Metres.	$Q_m = 797 \cdot 22 \lambda^{\frac{1}{2}}$ in Cubic Metres.	C	Q in Cubic Metres.
0.394	0.010	0.79722	0.63000	0.50225
0.433	0.011	0.91974	0.62640	0.57613
0.472	0.012	1.04797	0.62396	0.65389
0.512	0.013	1.18166	0.62207	0.73508
0.551	0.014	1.32060	0.62043	0.81934
0.591	0.015	1.46463	0.61887	0.90642
0.630	0.016	1.61346	0.61744	0.99621
0.670	0.017	1.76706	0.61620	1.08886
0.709	0.018	1.92525	0.61500	1.18403
0.748	0.019	2.08789	0.61393	1.28182
0.787	0.020	2.25488	0.61295	1.38213
0.827	0.021	2.42609	0.61207	1.48494
0.866	0.022	2.60143	0.61130	1.59025
0.906	0.023	2.78080	0.61063	1.69804
0.945	0.024	2.96411	0.61000	1.80811
0.984	0.025	3.15129	0.60942	1.92046
1.024	0.026	3.34224	0.60886	2.03496
1.063	0.027	3.53691	0.60833	2.15161
1.102	0.028	3.73521	0.60784	2.27041
1.142	0.029	3.93709	0.60737	2.39127
1.181	0.030	4.14248	0.60693	2.51420
1.220	0.031	4.35132	0.60651	2.63912
1.260	0.032	4.56355	0.60612	2.76606
1.299	0.033	4.77918	0.60576	2.89501
1.339	0.034	4.99800	0.60543	3.02594
1.378	0.035	5.22012	0.60513	3.15885
1.417	0.036	5.44543	0.60485	3.29367
1.457	0.037	5.67389	0.60460	3.43043
1.496	0.038	5.90546	0.60438	3.56914
1.535	0.039	6.14018	0.60419	3.70984
1.575	0.040	6.37776	0.60402	3.85229
1.614	0.041	6.61841	0.60386	3.99659
1.654	0.042	6.86202	0.60371	4.14267
1.693	0.043	7.10855	0.60357	4.29051
1.732	0.044	7.35796	0.60344	4.44009
1.772	0.045	7.61021	0.60332	4.59139
1.811	0.046	7.86529	0.60321	4.74442
1.850	0.047	8.12316	0.60311	4.89916
1.890	0.048	8.38378	0.60302	5.05559
1.929	0.049	8.64714	0.60294	5.21371
1.968	0.050	8.91319	0.60287	5.37349
2.008	0.051	9.18192	0.60280	5.53486
2.047	0.052	9.45329	0.60274	5.69788
2.087	0.053	9.72729	0.60268	5.86244
2.126	0.054	10.00389	0.60263	6.02864
2.165	0.055	10.28306	0.60258	6.19637
2.205	0.056	10.56477	0.60253	6.36559

TABLE OF RESULTS—continued.

λ in Inches.	λ in Metres.	$Q_m = 797 \cdot 22 \lambda^{\frac{3}{2}}$ in Cubic Metres.	C	Q in Cubic Metres.
2·244	0·057	10·84902	0·60248	6·53632
2·284	0·058	11·13577	0·60244	6·70863
2·323	0·059	11·42500	0·60240	6·88242
2·362	0·060	11·71669	0·60237	7·05790
2·402	0·061	12·01083	0·60235	7·23472
2·441	0·062	12·30738	0·60233	7·41310
2·480	0·063	12·60634	0·60231	7·59292
2·520	0·064	12·90767	0·60229	7·77416
2·559	0·065	13·21138	0·60227	7·95682
2·598	0·066	13·51743	0·60225	8·14087
2·638	0·067	13·82580	0·60223	8·32631
2·677	0·068	14·13649	0·60222	8·51328
2·717	0·069	14·44947	0·60221	8·70162
2·756	0·070	14·76472	0·60220	8·89131
2·795	0·071	15·08224	0·60220	9·08252
2·835	0·072	15·40199	0·60220	9·27508
2·874	0·073	15·72398	0·60220	9·46898
2·913	0·074	16·04818	0·60220	9·66421
2·953	0·075	16·37458	0·60220	9·86077
2·992	0·076	16·70156	0·60220	10·05768
3·032	0·077	17·03391	0·60220	10·25782
3·071	0·078	17·36681	0·60220	10·45829
3·110	0·079	17·70186	0·60220	10·66006
3·150	0·080	18·03903	0·60220	10·86310
3·189	0·081	18·37832	0·60220	11·06742
3·228	0·082	18·71970	0·60220	11·27300
3·268	0·083	19·06318	0·60220	11·47985
3·307	0·084	19·40873	0·60220	11·68794
3·347	0·085	19·75634	0·60220	11·89727
3·386	0·086	20·10601	0·60220	12·10784
3·425	0·087	20·45771	0·60220	12·31963
3·465	0·088	20·81144	0·60220	12·53265
3·504	0·089	21·16719	0·60220	12·74688
3·543	0·090	21·52494	0·60220	12·96232
3·582	0·091	21·88468	0·60220	13·17895
3·622	0·092	22·24641	0·60220	13·39679
3·661	0·093	22·61011	0·60220	13·61581
3·701	0·094	22·97576	0·60220	13·83600
3·740	0·095	23·34337	0·60220	14·05738
3·780	0·096	23·71292	0·60220	14·27992
3·819	0·097	24·08440	0·60220	14·50363
3·858	0·098	25·45780	0·60220	14·72849
3·898	0·099	24·83310	0·60220	14·95449
3·937	0·100	25·21031	0·60220	15·18165
3·976	0·101	25·58941	0·60220	15·40994
4·015	0·102	25·97039	0·60220	15·63937
4·055	0·103	26·35324	0·60220	15·86997
4·094	0·104	26·73796	0·60220	16·10160
4·133	0·105	27·12452	0·60220	16·33439
4·173	0·106	27·51182	0·60220	16·56762
4·212	0·107	27·90319	0·60220	16·80330
4·262	0·108	28·29527	0·60220	17·03941
4·301	0·109	28·68917	0·60220	17·27662
4·331	0·110	29·08488	0·60220	17·51491

(*Students' Paper, No. 318.*)

"Methods adopted in Constructing the Glasgow Central Railway (Bridgeton and Trongate Contracts)."¹

By CHARLES DAVIDSON BARKER, Stud. Inst. C.E.

THE work described in this Paper comprises 3 miles of underground construction (the top of the railway being only a few inches from the surface of the streets) and $\frac{1}{2}$ mile of cutting. The chief difficulties to be overcome were to construct a railway beneath the busy streets of the city of Glasgow, without interfering with the traffic and without damage to the valuable properties which are in many cases within a few feet of the railway.

Operations were begun at the east end of the Bridgeton contract; at Anderston Cross, which is at the west end of the Trongate contract; and in Monteith Row, which is the north boundary of Glasgow Green, and where the Bridgeton and Trongate contracts meet. In the construction of the portion of the railway through Glasgow Green, the method adopted was to some extent different from that used later in constructing the railway under the streets. The ground, which has a considerable side-slope, was first excavated, to form a fairly level surface about 5 feet below the intended level of the soffit of the covered way. Upon this was erected a 3-ton steam-derrick, with a 50-foot jib, mounted on bogies which ran on rails. This crane was moved backwards, trenching for the side-walls as it went. The radius at which the jib of the crane worked was sufficient to allow the skips to be emptied direct into carts standing at the head of the slope. When one trench had been excavated, the bricklayers commenced building the side-wall, the bricks being supplied to them by hand-cranes. The large crane was meanwhile used for sinking the trench for the opposite wall. When this side-wall was built, the ribs were set and the building of the arch was begun. The crane, in the meantime, was moved backward 24 feet, and the labourers

¹ This Paper was read and discussed at a meeting of Students on the 10th March, 1893, and has been awarded a Miller Prize, Session 1892-93.

prepared another length of trench for the bricklayers. On an average, a double squad of ten navvies (day- and night-work), could excavate and concrete a 24-foot length on each side of the railway every week, where the ground was good. Progress in the wet running sand at the east end of Monteith Row, where the interstices between the piles had to be packed with hay and manure, was much slower.

For facilitating the removal of spoil from the trenches in the central portion of the Trongate contract, and the dumping from Anderston (the west end of the contract), a platform was erected in Monteith Row alongside the temporary railway, large enough for four carts to tip at one time into wagons standing on the line. This platform made the greatest possible "lead" for the horses— $1\frac{1}{2}$ mile. On the opposite side of the line was a similar platform, from which the wagons were filled with bricks and run down the tunnel to supply the bricklayers working in London Street. This temporary railway, which was $\frac{1}{2}$ mile long, led to the tip at the Fleshers' Haugh, a low-lying portion of Glasgow Green, in which all the spoil from the works was deposited.

One of the first pieces of work carried out on the Bridgeton contract was the underpinning of a large retaining-wall, which runs for 1,100 feet along the west side of the Caledonian Railway Company's London Road branch railway. The operations in connection with this had to be carried out without interfering with the traffic along that line. The chief difference between the underpinning of such a wall as this, where the contractor is not hampered by vehicular or pedestrian traffic, and the underpinning of a block of houses at the side of a busy street is, that underpinning can be effected from the surface and at many points, still allowing the men a reasonable amount of room for their operations. When underpinning a block of buildings, it is sometimes found convenient to carry on all the operations below the surface without in any way interfering with the surface. Such a case is referred to later. In underpinning houses, those portions which are solid from foundation to roof must be underpinned first, after which the spaces between them are underpinned in short lengths in the usual way.

The ground was first excavated to within a few inches of the bottom of the wall. Raking struts were then erected against the wall, their lower ends being firmly placed against stay-piles 10 feet long driven 7 feet into the ground. The main head-tree, which was a 12-inch by 12 inch pitch-pine log, was laid below the outer edge of the footings, its ends both having a bearing of

2 feet upon timbers which had first been laid in crosswise for the purpose. The excavation was then carried down 4 or 5 feet, when one or, if necessary, two head-trees were put in from below. These were shorter than the main head-tree, as otherwise they could not have been got in from below. The trench was then sunk down to the bottom, timbered as shown in Fig. 1, Plate 7, and the concrete was put in. The brickwork was then built up to 5 or 6 feet from the bottom of the foundation of the existing wall, from which point it was first carried up in the back half of the trench only, to 9 inches from the bottom of the footings, when it was keyed in with wedge-shaped bricks. The two shorter head-trees at the back were thus built in. At the extreme west end of the Trongate contract, iron wedges were at first used for keying the underpinning to the foundations of buildings, but these were soon dispensed with in favour of the wedge-shaped bricks. When the back-half of the underpinning was being built (all headers) in every second course in front a stretcher was laid in sand. These were afterwards removed, so as to enable the front portion of the underpinning to be bonded with the back portion. The front portion of the underpinning was then put in—one half of the front being brought up below the main head-tree and keyed behind it, and the pocket being afterwards built up to the underside of the main head-tree.

During these operations other men underpinned a similar length about 20 feet away, and the space between them was then excavated and underpinned in short lengths. This was effected by moving the main head-trees forward one length, their tail-ends resting on the brickwork already built, and their leading ends resting on the 6-inch by 3-inch timbers laid crosswise as already described. As each main head-tree was moved forward, the pocket or portion of brickwork left unkeyed in the last length of underpinning was completed. When a continuous stretch of underpinning was finished, it was faced with specially pressed facing bricks. Every fourth course of these were headers, bonding the facing work into the underpinning behind. When the bricklayers first began to underpin this wall, they were so unaccustomed to the confined position in which they found themselves, that they only built about $1\frac{1}{2}$ or 2 cubic yards a day. After they had become accustomed to the work they were able, under favourable circumstances, to increase their day's work to 4 cubic yards. While these operations were going on, the masonry retaining-wall on the opposite side was also built, Fig. 1. After these walls were completed, it was decided to place steel struts between

them at their highest part. As the "dumpling" had already been removed, a small gantry was built in the cutting and carried on bogies laid on rails. The struts, which weighed about 6 tons each, were brought along the siding behind the new retaining-wall and slid down greased rails on to the top of the gantry, from which they were placed in their final positions by hydraulic jacks.

The engineers having decided to sheet-pile the streets before beginning to build the covered ways, the contractors had to design and construct piling-frames suitable for the purpose. Figs. 2 and 3 give end and side elevations of these piling-frames, which were so constructed as not to interfere with the traffic. The main posts were pitch-pine, 14 inches square, resting on runners. Over the tops of these 12-inch by 12-inch logs were fastened and secured to the uprights by iron angle-bars. The main posts were tenoned into these logs, on the top of which were laid other logs to carry the rails on which the upper frames ran. There was room for the upper frames to pile for a distance of 15 feet without the lower frame being shifted. On each of the two upper frames was a boiler, and a steam-winch for working the monkeys. They were thus two complete piling-frames, independent one of the other. The weight of each ram was about 3 tons, and the weight of the whole frame, ready for piling, was 45 tons. On account of the traffic, the contractors were only allowed to carry on piling operations between 7 P.M. and 7 A.M. Between these hours it was found that about nine or ten double piles 25 feet long could be driven on each side of the piling-frame. The greatest number of piles ever driven in in a night's work by a piling-frame was twenty-seven. That was fourteen for one side, and thirteen for the other. To enable this number to be driven, both rams had to be kept going at once. This plan, however, had to be given up, as it caused excessive vibration. The best week's work in the Anderston district was one hundred and seven double piles. The worst week's work was seventy-five.

The number of strokes required to drive one pile home varied between 230 and 880, the fall of the ram being about 2 feet. A gang of men was constantly employed trenching in advance of the piling to a depth of from 7 to 9 feet. It was observed that less damage was done to property when the ram was heavy and the fall small, than when the ram was small and the fall great. The average rate of striking was about seventeen blows per minute.

About 3 miles of sheet-piling were driven by these machines, four of which were employed. On the top of each piling-frame were two winch-men, one fire-man and two signal-men. Below,

there were two guides, two monkey-men, one lamp-man, one watchman and ten labourers. There were two joiners making piles, and with them one labourer—total, twenty-four men. When the piling operations were far enough advanced, the construction of the covered ways was at once proceeded with. Figs. 4 and 5 illustrate the way in which one form of covered way was constructed: 12-inch by 12-inch pitch-pine logs, 34 feet long, were laid across the street on a Sunday, resting on the tops of the sheet piling. A 6-inch by 12-inch runner was fastened along the tops of these piles, in order to distribute the weight of the logs upon the piling. These logs had spaces of about 4 inches left between them, so that when the brickwork of the covered ways was completed, the concreting of the spandrils might be handily done, by simply emptying the concrete through the spaces between the logs. At intervals of 24 feet, a hatch-way was left in the logs on each side of the street. These were formed by cutting spaces out of three of the logs, and supporting the ends of them on 14-inch by 7-inch timbers, which were bolted at each end to two of the un-cut logs which rested on the piles. On each side of this hatch-way cart-rails were laid, and a crane was placed in position for removing the excavation. On Monday morning the men began to excavate beneath the logs to a depth of 6 feet below them.

When the top of the excavation had been removed, the side-trench below the crane was begun, and, when finished and concreted, the bricklayers began to build the side-wall in it. When excavating a side-trench such as this, a gang of twelve men could send away about forty-five loads a day to the tip. When putting in the concrete foundation, a gang of twelve men—nine above and three below—could finish a 24-foot length in five hours. During the night the crane was moved into position over the hatch-way at the opposite side of the street, and the navvies excavated this length. As soon as this second wall was built by the bricklayers, a gang of joiners and their labourers set the ribs for the arch. They took about five hours to get three ribs into position and ready for building. The bricklayers then built the arch.

In building the covered way in Dalmarnock Road, it was found that a bricklayer could build about 2 cubic yards of brickwork in a day. This is less than that done in building the common brickwork of the underpinning referred to, because the facework in Dalmarnock Road had to be built up with ordinary brickwork; and then the building of the refuges in the covered way took up a

considerable time. Further, as the building came up to each setting, the struts and walings had to be removed. When possible, the settings were taken out during the bricklayers' meal hours; but this could not always be arranged. A much better day's work could be done by the bricklayers when building the arch than when building the side-walls of this covered way, for several reasons: No time was lost in removing settings, the bricks were more easily and therefore more quickly supplied, and the bricklayers had more room to work in up to the "keying-in" point.

The following notes relating to the building of side-walls and arches may be of interest:—

An 18-foot length of arch was begun by six bricklayers, served by eight labourers. Seventeen hours were occupied up to the keying-in point. It then took two bricklayers and three labourers three hours to key it. A 24-foot length of side-wall was begun by five bricklayers, served by seven labourers. It took them twenty-five hours to complete it.

About every second Sunday, when the work was proceeding at its best, about 50 lineal feet of the street surface was restored. A gang of men began about midnight on Saturday to lift the logs over the arch, and to re-lay them for the construction of a new length ahead of the building. Those rings of the arch which could not before this be laid on account of the logs, were now completed by the bricklayers; any concreting of the haunches which had not yet been done was also finished, the asphalt was laid over it, the necessary filling put in, and the causeway restored. By the methods described, the completed covered way (excepting the removal of the "dumpling," and laying the concrete invert) advanced at two faces in Dalmarnock Road at the rate of 100 feet per month, when progress was most rapid. The navvies worked in double shifts.

When nearly the whole of the brickwork in Dalmarnock Road was completed, and the street had been restored, the removal of the "dumpling," and laying the concrete invert was proceeded with. For this purpose, spaces had been left in the arch at three different points, at each of which a crane was placed, the excavation being taken out eastwards and westwards from these points. A gang of sixteen men and a ganger, with a man and a boy at the crane (half the navvies dealing with each face), could turn out every week 400 cubic yards of excavation, and mix and put in 45 cubic yards of concrete invert (about 30 lineal feet).

Along Argyle Street, which is probably the busiest in Glasgow,

as the roof of the railway was formed of girders with jack-arching between them, special arrangements had to be made for getting these into position. Fig. 6 illustrates one of the methods adopted for constructing this form of covered way. Logs were not stretched right across the street, but 12-inch by 12-inch logs, 14 feet in length, were rested on the piling at one end, and at the other end were laid on bearing-timbers close up to the nearest tram-rail. The trenches for the walls were then excavated and timbered, the excavation being removed by the crane. When the trench was bottomed and concreted, the brickwork was commenced, the crane meanwhile being moved forward to deal with another length of trench in a similar manner. When the crane had excavated a sufficient length on one side of the street to allow room for four or five girders to rest on this wall, it was shifted over during the night to the opposite side, and the operations were repeated. The contractors had to carry on these operations inside a barricade 70 feet long and about 12 feet wide, and no two sets of operations could be carried on within 100 yards of each other. When the side-walls were sufficiently advanced, the girders were placed in position on Sunday. As a rule, four girders were placed at each point where the work was going on. The greatest number placed in one day by the contractors was thirteen. A gang of 30 or 40 men began at midnight on Saturday to remove the road and excavate a sufficient length to get in, say, four girders. That means, they had to remove the material between the side trenches for a length of 34 feet, and a breadth of 21 feet to a depth of 4 feet 6 inches. This they usually accomplished by 6 A.M. on Sunday morning. Then the first girder was drawn below the jibs of the two travelling steam-cranes. Chains were tied round the girder and it was raised and run forward and laid on greased rails laid on the top of the side-walls. The girder was then moved forward on these rails by crowbars, and placed in position at the end of the excavation farthest from the cranes. The first girder had not to be "pinched" forward on the rails the whole length of the excavation, as the two cranes could carry the girder (weighing $3\frac{3}{4}$ tons) at a radius of 15 feet, and so could set it down that distance from the edge of the excavation. The two last girders were laid by the cranes in their final positions. When the two first girders were in position and had their tie-rods adjusted, the bricklayers began to build up the walls at the ends of the bays between the girders, while the joiners commenced hanging the centres for the jack-arching. As soon as the building of the end walls was finished, the bricklayers began to build the

jack-arches. Meanwhile, the navvies mixed the concrete for the haunches of the jack-arching and the backs of the side-walls. That being finished and the asphalt spread, the causeway was re-laid. These operations usually occupied until 3 A.M. or 4 A.M. on Monday morning.

Fig. 7 illustrates some interesting work which was done at Glasgow Cross. Before putting in the side-walls, the houses at each side had to be underpinned. To do this, a floor of 6-inch by 3-inch timber was laid down on the south side of the street, on a Sunday, and carried by 12-inch by 12-inch logs 24 feet long. From a yard at the south-east corner of the Cross, the excavation beneath this timbering was removed, down nearly to the bottom of the foundations of the existing buildings, and the houses were underpinned in short lengths. In this case the excavation for the underpinning extended 2 feet in front of the old foundations. This gave the workmen a space of 7 feet by 4 feet to work in. When the whole block was underpinned, the remaining excavation was removed, and the concrete foundation for the station walls were put in. The houses on the north and south sides of the street having been underpinned, and the station walls built, the north wall was built across the Saltmarket. A crane was placed at the west side of the Saltmarket, and a heading, 6 feet high and 10 feet 6 inches wide, was driven under this street until it reached the part of the north wall already built. The spoil was run back in trolleys to within reach of the crane, which emptied their contents direct into the carts. The trench for the side-wall was then taken out "back-handed," and the wall was built under the street. This heading was driven with only a foot of cover, when the traffic was at its height, the 6 inches of concrete under the causeway rendering this possible. The head-trees were placed close together.

The houses having been underpinned and the side-walls of the station built, the girders had to be placed in position. This, as the street had to be lifted, could only be done on Sundays. About 30 men began at midnight on Saturday, but as about 250 cubic yards of excavation had to be removed to allow room for two girders, it was usually after 11 A.M. on Sunday before everything was in readiness for placing them. The girders, which weighed over 10 tons, were brought on to the ground by a "janker," which deposited them on greased rails at the side of the excavation. They were then "pinched" forward on the rails close to the edge of the excavation, when they were lowered on greased rails on to another set of rails lying along the bottom of the excavation. They were then "pinched" along these until they were just over their perma-

nent position, and were then lowered on to the bed-plates by jacks. It was found that after these large girders were in position, the day was usually so far advanced that it was useless to begin the jack-arching. This was built during the week below the timbering.

The following are some notes of the time required to carry out work in connection with the covered way, shown on Figs. 4 and 5, at the Trongate, one of the busiest portions of Argyle Street. At this place, the crane had to be kept at the south side of the street, because the north tram-rail was too close to the sheet-piling on the north side of the covered way to allow room for a hatchway, or for a crane to stand. This necessitated the excavation from the north trench being thrown up on to the "dumpling," then thrown across the "dumpling" to the south side, and then drawn up by the crane.

A gang of 12 excavators and 1 surface-man, looking after the skip as it came up, began to excavate a new 24-foot length at 10 A.M. on Monday, the 5th December. When they stopped work on Wednesday evening they had taken out the whole width of excavation down to 6 feet 6 inches below the logs—twenty-four hours. On Thursday the 8th, they began to excavate the trench for the side-wall at the north side, i.e., the side farthest from the crane, 6 men digging, 3 men throwing, and 3 men filling the skip. On Friday morning, the 9th, they were 5 feet down. The ground was stiff clay from 8 feet below the underside of the logs. A great deal of water found its way into this trench. On Saturday morning they were 8 feet down, on Monday morning 10 feet down, the excavation requiring two throws to the top of the dumpling. On Tuesday morning, the 13th, they were 13 feet down, the excavation requiring three throws (two platforms). This north trench was finished at mid-day on Wednesday, the 14th. The concrete for the foundations was then mixed on the top of the "dumpling" and put into the trench in five hours. The bricklayers began on Thursday morning to build the wall. On the same morning the navvies also began to trench on the south side, and bottomed this by 11 A.M. on Saturday, the 17th, having thus only taken 22 hours to finish this length. That is to say, it took fully twice as long to excavate a trench when the excavation had to be thrown over the dumpling by hand before it was drawn up by the crane, as it did to excavate the same length of trench when the excavation was drawn straight up by the crane. The second trench, having been bottomed by 11 A.M. on Saturday morning, was forthwith concreted. This occupied four hours, and enabled the bricklayers to begin to build the wall on Monday morning.

The usual time taken to excavate a 24-foot length of the covered way shown in Fig. 6 where the ground was fair, was about forty-four hours, twelve men and a ganger working at it. Depth of trench 23 feet. This included the time taken in concreting.

The following are some notes of the time taken to excavate such a trench when there was 2 feet 3 inches of water in the bottom, the material being sand. A gang of ten men and a ganger began on Thursday morning, the 8th December. On Friday morning they were 5 feet down and were hammering in 8-foot runners. On the same afternoon the logs were laid over the trench. On Saturday morning the men had excavated 8 feet 6 inches down. On Monday morning they were 11 feet down, and on Tuesday at same time they were 16 feet down. At dinner-time on Tuesday they reached water, and a pulsometer pump was put in. On Wednesday morning (the 14th) they were 9 inches from the bottom. That evening the men worked late and got half the length bottomed and concreted by 10 P.M. On Thursday they got the second half bottomed and concreted by 9.30 P.M. Total time, 67 hours. This was quicker than was usually accomplished in these trenches where water and sand had to be dealt with. Five bricklayers began on Friday morning (the 16th) upon this length, and finished it at 2 P.M. on the 22nd, thus taking forty-eight hours.

When a length of arched covered-way was being restored, there were usually one or more points where the girders for the other form of covered way were being put in. The excavation which was removed to get these girders into position, was utilized for filling in over the concrete in the spandrels of the other covered-way. This saved a great amount of cartage.

The following are some notes taken in connection with the work done on Sunday, the 18th December, 1892. On this day a 60-foot length of street over the arched covered way was restored in London Street. 24 feet of street was lifted in the Trongate and logs were laid down, so that the navvies at this point might be kept employed during the ensuing week. Also 4 girders were placed in position in Argyle Street at the corner of Glassford Street, two girders being of the usual weight ($3\frac{1}{2}$ tons), and the other two being considerably heavier; and somewhat further west still 5 roof-girders were placed in position. It is particularly to the two last mentioned points that these notes refer. At all four points the men began work at midnight on Saturday. At Glassford Street 107 cubic yards of earth had to be removed before there was room for the girders, and at St. Enoch's Wynd 115 cubic yards had to be removed. There was a travelling crane at each of these points.

At 8 A.M. on Sunday morning the crane which had been removing the earth at St. Enoch's Wynd arrived at Glassford Street to aid in putting in the four girders there. At 8.9 A.M. the first girder, having been drawn under the jibs of the two cranes, was slung by them about 30 yards from the side of the excavation. At 8.11 A.M. it was placed in position. At 8.16 A.M. girder No. 4 (light) was slung and run forward. Greased rails were laid in position for it on the tops of the side-walls. At 8.26 A.M. it was placed on its bed-plates. At 8.34 A.M. girder No. 2 (heavy) was slung and run forward. At 8.38 A.M. it was placed in position. At 8.44 A.M. girder No. 3 (heavy) was slung and run forward. At 8.52 A.M. it was placed in position.

When the last girder was in, and the tie-rods were tightened, the bricklayers began to build up the plumb walls at the ends of the girders. While they were doing this, the joiners placed the centres ready for the jack-arching. When the two cranes finished placing the girders at Glassford Street, they travelled to St. Enoch's Wynd, to place the girders there. The excavation here had been completed by 9 A.M. on Sunday morning; but it was 10.15 A.M. before the ground was ready for the girders, because a large water-pipe which was in the way had to be removed. By 11.0 A.M. all four girders were laid in position. When the tie-rods here were tightened up, the bricklayers began to build the end walls.

At 11.20 A.M. the plumb walls at the end of the three bays at Glassford Street were completed. At 5.30 P.M. the jack-arching at St. Enoch's Wynd was completed. At 6.50 P.M. concreting over three of the arches at St. Enoch's Wynd was finished—two of them asphalted. At 11 P.M. all the asphaltting at St. Enoch's Wynd was finished. At 11.10 P.M. the causeway was finished at Glassford Street between the rails, and half finished north of the rails.

In London Street on this occasion, the street was restored at 3 A.M. on Monday morning. At St. Enoch's Wynd it was 5 A.M. before the street was finished and ready for the traffic of Monday morning.

On this occasion 48 carts and horses were out, the total number of working hours being 1,210, or 25 for each cart and horse. All the excavation taken out at Glassford Street and St. Enoch's Wynd was required to fill over the covered-way in London Street.

About 240 men were employed at these four points. On the Sunday referred to, the restoration of part of Dalmarnock Road was also completed.

The removal of the "dumpling" from the covered way in the west end of Argyle Street was effected by simply leaving out a

5-foot length of side-wall between two girder-blocks, placing a crane at this point, and then proceeding in the same way as in Dalmarnock Road.

The contract sum for the works described was £625,000. The engineers for the undertaking are Mr. George Miller Cunningham, M. Inst. C.E., of Edinburgh, and Mr. Charles Forman, M. Inst. C.E., of Glasgow. The consulting engineer is Mr. J. Wolfe Barry, Vice-President Inst. C.E. The resident engineer until the beginning of 1892, was Mr. Thomas Nisbet, Assoc. M. Inst. C.E., who was succeeded by Mr. Donald A. Matheson, Assoc. M. Inst. C.E. The contractors were Messrs. Charles Brand and Son, and the Author has acted as their engineer since September 1892.

The Paper is accompanied by eighteen drawings and a map, from a selection of which Plate 7 has been compiled.

(*Students' Paper, No. 323.*)

"The Manufacture and Efficiency of Armour-Plates."¹

By DAVID CARNEGIE, Stud. Inst. C.E.

It is nearly forty years since armour-plate was introduced as a protection for war-ships. From that time there has been a constant struggle for superiority between projectiles and armour. It may be said that almost equal advances in the manufacture of both plates and projectiles have been made, chiefly owing to the strong competition between British and foreign manufacturers.

MATERIALS.

Iron plates were introduced by the French, and applied to float-ing-batteries during the period 1854-58. The "*Gloire*," launched in 1860, was the first sea-going ship to which armour-plates were applied. In the year 1861, the British Government formed a "scientific committee for the purpose," says Dr. W. Pole² (one of its number), "of investigating generally the application of iron to defensive purposes in war." After an extensive series of experiments, the committee decided that "the most suitable material was simple malleable iron." For many years that material was used, while the thickness of the armour-plates varied. The tough malleable nature possessed by wrought-iron gave it a good place as long as the material of which the projectiles were made had a constant value.

But increased strength of guns, attended with higher projectile-velocities, called for a stronger material than wrought-iron; consequently the introduction of steel armour-plate excited considerable interest. Its first appearance for trial was in 1876, at the Muggiano proving-grounds near Spezia,³ and to Schneider must be attributed the credit of having first manufactured steel armour-plate. A spirit of rivalry was aroused among English

¹ This Paper was read at a meeting of Students on the 14th April, 1893, and has been awarded a Miller Prize, Session 1892-93.

² Minutes of Proceedings Inst. C.E., vol. xcvi. pp. 65, 66.

³ Trans. Inst. N. A., 1891, vol. 32, p. 138.

manufacturers on the advent of the foreign steel-plates, and in a short time Messrs. Cammell and Co. and Messrs. Brown and Co., of Sheffield, the renowned iron-plate makers, converted their plant to suit the manufacture of steel armour-plates. In the year following this important advance in the manufacture of steel plates, a compound armour-plate was introduced by Mr. A. Wilson, and by many it has been considered superior to the solid steel-plate.

A further advance was subsequently made by the introduction of nickel into the solid steel-plates.

MANUFACTURE.

Many methods have been proposed for the manufacture of armour-plates, and if the expense entailed in conducting experiments were not so great, the development of various plans suggested might lead to successful and practical issues. There are three principal methods of manufacture carried on at the present time :

(1) "Wilson's Compound Armour-plate" consists of a soft tenacious wrought-iron plate, united with a hard steel-plate in the ratio of one-third steel to two-thirds iron. The iron-plate is first manufactured so as to fit into an iron mould of the shape of the compound plate required. The space between the iron-plate and the inside of mould is filled with molten steel, which unites with the wrought-iron plate, making the line of contact difficult to discern. The need of a tough back in the compound plate involves the removal of all foreign matter from it, and for this reason the iron-plate is carefully composed of many thin plates of puddled iron. Iron can never be wholly free from impurity, owing to the fact that while it is being manufactured from the "pig" in the puddling process, by the partial extraction of carbon and other impurities, the liquid cinder or slag permeates the mass. Although squeezing the balls at a welding-heat largely effects the removal of the slag and gases, yet it only reduces the films of cinder, leaving the whole mass like a network of slag, the interstices being filled with crystals of iron.

The presence of phosphorus and silicon also—elements difficult of removal—is detrimental to perfect homogeneity and malleability. To what extent phosphorus and silicon diminish the value of the armour-plate can only be understood by considering the influence they exercise over the particles which together

make up the plate. Mr. W. F. Dumfries has given an interesting account of the effects produced in iron-plates by phosphorus and silicon, and points out that these elements diminish the "cohesive attraction between the particles of iron enclosed in the slag," which inclines to produce a crystalline instead of a fibrous structure when the material is cold.¹ Prof. Roberts-Austen² says, "any circumstance which inclines to produce crystallization must affect the malleability." It is therefore clear that the presence of those elements in the plate impairs its powers of resistance.

The iron-plate after manufacture is heated to a high temperature and pressed horizontally into the iron mould already described. The mould and plate are swung into a vertical position and lowered into a pit for convenience of casting. Over the open space in the mould is fitted an iron trough lined with fireclay, through the bottom of which are numerous perforations; so that the steel, which is run into the trough from the ladle, may be as far as possible free from slag when it enters the mould. The trough also causes the molten metal to stream into the mould like water from the rose of a watering-can, diminishing the inrush of air drawn with the falling body of molten metal into the mould, which often causes unsound castings that can never be made good by working the material. The compound body, when sufficiently cool, is removed from the mould and gradually re-heated in a furnace. The mass is then submitted to hydraulic pressure, after which it is passed through the rolling-mill and reduced to the thickness required. The next operation is bending the plate to the curvature of the ship's side, which is done under a powerful hydraulic press. Finally, the plate is machined and drilled.

(2) The second important method of manufacture is that known as the Ellis process. It consists in combining a soft tough iron back with a hard thin steel-plate, by casting a layer of steel between the two. The process is conducted in the following manner:

With the same care as in the method last described, the iron-plate which forms the back of the armour-plate is made a little larger than the requisite finished dimensions. The thin hard steel face-plate of the armour is next made, and when both plates are cold, they are held in a position parallel to one another, with their faces kept a few inches apart by strips bolted to the iron-plate along the sides and bottom. The two plates are next

¹ Proceedings of U.S. Nav. Inst., 13, p. 369.

² "Introduction to the Study of Metallurgy," p. 7.

removed to a heating-furnace, and when the whole mass has been brought to a red heat, it is taken to the casting-pit and fitted in a vertical position, after which the space between the two hot plates is filled with molten steel, causing the three laminæ to unite. The subsequent operations are conducted similarly to the method described in the first case. In conjunction with the manufacture of the Ellis compound plate, Captain Tressider has lately introduced a mild steel back, containing about 2 per cent. of nickel to replace the soft iron.

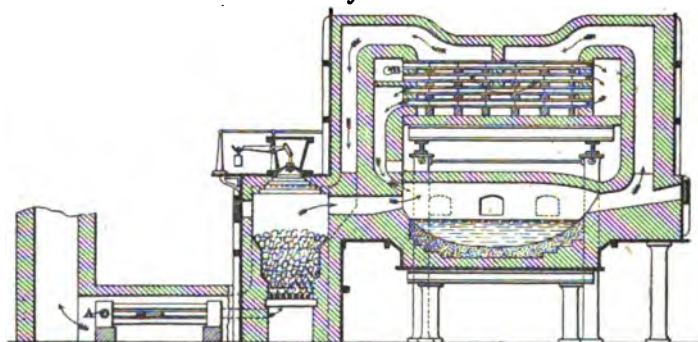
(3) All-steel armour-plate is made by nearly every armour-plate maker.

Steel armour-plates are classified according to the material alloyed with them. The method of manufacture is, however, practically the same for all solid steel-plates. The principal points of interest in the manufacture are found in tracing the development of each process from the steel-furnace. Carbon chemically combined with iron may be said to be the distinguishing element between wrought-iron and steel; but since this fact was known, it has been proved beyond doubt that the chemical combination of other elements greatly modifies the physical properties of the compound.

The furnaces usually employed for the manufacture of steel for armour-plates are the Bessemer and Siemens-Martin—preferably the latter. Another good furnace, *Fig. 1*, invented by Mr. Radcliffe, of the Woolwich Arsenal, is used with success both in the Royal Arsenal, for the manufacture of ordnance and ammunition, and at the Thames Iron Works, in the production of experimental steel armour-plates. Although these furnaces differ in construction, the object of all of them is the same, namely, the decarburization by oxidation of the “pig” and “scrap,” or the “pig” and “ore,” according to the process employed; and afterwards the addition of a re-carburizing agent, such as ferro-manganese or spiegeleisen, in the quantity corresponding with the required percentage of carbon. When a special mixture is required—for instance an alloy of nickel and steel—care must be taken that a minimum amount of nickel be oxidized; and also that it be added in a liquid condition to the charge at as early a stage in the manufacture as possible, so as to increase the homogeneity of the steel and to diminish the risk of producing “blowholes.” To prevent oxidation in the bath of the furnace, it is necessary to keep a good slag over the molten metal. The recarburizing agents are added to the charge as in the ordinary method. Nickel may also be added in the liquid state to the steel in the furnace,

just before tapping. The amount usually added is 2 to 5 per cent. From the furnace an ingot of steel is run, sufficiently large for the armour-plate required. It is allowed to solidify gradually, to prevent as far as possible internal strain or rupture. A perfectly sound ingot is rarely obtained owing to the formation of "blow-holes" in the steel. Attempts have been made to prevent the occurrence, by mechanically agitating the steel in the furnace, and also whilst in the ladle; but neither plan has been successful in freeing the steel entirely of blow-holes. The ingot is removed to the re-heating furnace, where it is important that the heat be applied to the mass very gradually and maintained at a proper temperature, to prevent internal injury either from unequal heating or over-heating. When the ingot is heated throughout to a bright red heat, it is reduced to the size required under the steam-hammer, or in the rolling-mill.

Fig. 1.



RADCLIFFE STEEL FURNACE.

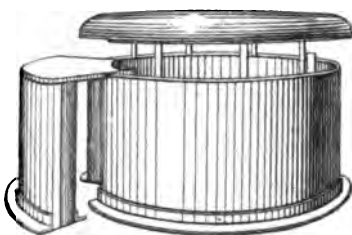
Although the value of the material is much increased in these operations, yet an ingot with blow-holes in it cannot be made good, however much rolling or hammering it receives; and its value is often diminished by the elongation of these holes into fine tubular threads, forming in many cases the seat of a "through crack" when the plate is subjected to fire. A few months ago the Author observed that an armour-piercing projectile, some time after it was hardened, cracked longitudinally from point to base. When the fracture was revealed, the metal was found to be good with the exception of a long plain narrow streak from end to end, which presented the appearance of a blow-hole drawn out like a thin cord. This is just as liable to exist in armour-plates, and to prove as injurious.

The two principal methods of hardening armour-plates known in England and in America, are respectively the "Tressider" and "Harvey" processes. The former process consists of laying the heated armour-plate below a number of pipes placed horizontally like a grid-iron. The pipes are about $\frac{3}{4}$ inch in diameter, and along the lower side of each are drilled holes about $\frac{1}{8}$ inch in diameter, to allow water ejected from the pipes under pressure to play upon the hot plate. The injurious effects produced by the ordinary method of quenching in a water-bath, due to the irregular abstraction of heat from the surface of the body, owing to the envelope of steam which separates it from the water, are considered to be thus overcome without any reduction in the hardness of the armour-plate.

In the Harvey process, the face of the armour-plate is hardened by cementation. The plate is bedded in sand to about two-thirds of its thickness at the bottom of the furnace. The exposed part is packed closely with charcoal or other carbonaceous matter. The furnace is maintained at a high temperature long enough to allow the steel to absorb the required amount of carbon. The plate is then removed from the furnace and allowed to cool slowly until it reaches a dull red heat, after which it is suddenly chilled, either by sprays of water or by being plunged bodily into cold water.

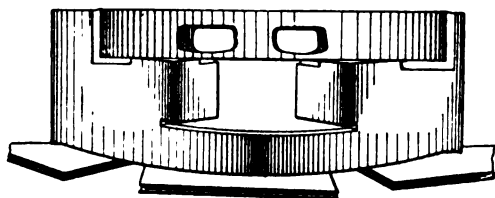
Neither of these processes can be said to give absolutely

Fig. 2.



CONNING TOWER.

Fig. 3.



CASEMATE.

satisfactory results. The great weakness in all such artificial methods of hardening is, that they are not applicable to armour which has to be curved to the lines of a ship. The cost of conducting the operations is also considerable. Not only has the

plate to be heated repeatedly in the Harvey process, but it has often to be machined all over after the hardening is completed, to remove the irregularities caused by warping. When difficulty is experienced in hardening small flat plates, it will be readily understood how impossible it is to apply such processes of hardening to the forms of armour illustrated in *Figs. 2* and *3*. The former *Fig.* shows the conning-tower for the Spanish cruiser "Infanta Maria Teresa;" and *Fig. 3* is a view of the casemate for the protection of a 6-inch gun on H.M.S. "Hawk."

EFFICIENCY OF ARMOUR-PLATES.

The material of which an armour-plate is composed should have a resistance to penetration equivalent at least to the total energy of the projectile at the instant it strikes. The difficulty of obtaining such material increases daily, owing to recent improvements in the manufacture of forged-steel projectiles, and the increased velocities at which they strike the plates. When wrought-iron plates were used, their combined tenacity and toughness proved sufficient to resist the best projectiles then produced; and, although perforation was sometimes effected, the damage done to the plate was local.

Steel armour-plates, with their increased resisting-properties, have done much to oppose the penetration of the forged chrome-steel projectiles, and perforation has in many instances been checked by reason of the plate gradually absorbing the energy of the shot before it has completed its passage through it. This has, however, been not infrequently attended by cracks extending throughout the entire length of the plate. It was with a view to combine the qualities possessed by the steel and the iron plates that compound armour was introduced. The steel plate, with its high resistance to surface penetration, coupled with a tough malleable backing of wrought-iron, gave promise of being free from the weakness of former plates. If by repeated blows, under exceptionally severe trial, the hard face of the plate be penetrated, surface-cracks may appear, but the tendency to "through-cracking"—the inherent vice of all-steel armour-plate—is not great, because of the malleable body to which the hard plate is united. Compound plates have been condemned on account of a possible danger of the steel face becoming detached in fragments from the iron plate whilst under fire, thus exposing a surface totally incapable of resisting the projectile; but the union which exists between the two materials

has stood the most severe attacks of specially-hardened forged-steel projectiles, without much sign of such weakness.

Fig. 4 illustrates the front of a compound steel-faced armour-plate, tested by Messrs. Cammell and Company, after being fired at five times on the 27th of August, 1891. Although the striking-velocity of the 6-inch forged-steel shot was nearly 2,000 feet per second, it will be seen that the plate was hardly damaged, and it succeeded in breaking up and destroying every projectile hurled against it. The bulges in the rear of the plate were hardly perceptible.

Another compound plate, 8 feet by 6 feet by 10 inches thick, made by Messrs. Brown and Company of Sheffield, and surface-hardened by the Tressider process, was privately tested by

Fig. 4.



FRONT.

Government officials at Sheffield, on 4th August, 1892. *Fig. 5*¹ is a front view of the armour-plate after resisting and breaking up into many fragments the five 6-inch Holtzer Forged Steel projectiles fired at it. The weight of each projectile was about 100 lbs.; the average striking-velocity about 1,950 feet per second, and the energy nearly 2,655 foot-tons. A few fine cracks caused by each shot appeared in the plate, but they were so slight that they could only be seen by close examination. The maximum and minimum penetrations of the projectiles were 8 inches and 1·09 inch respectively, while the bulges on the back were very

¹ Reproduced from a photograph by the kind permission of the Editor of the *Engineer*.

Fig. 5.**FRONT.***Figs. 6.***FRONT.****BACK.**

small. On the whole the result is remarkably good, and further demonstrates that the united plates are capable of remaining intact even when exposed to the attack of the best projectiles.

Messrs. Cammell and Company have recently supplied to the British Admiralty 3 all-steel armour-plates for test. The results obtained were remarkably good: the first plate, of the same size as the compound plates referred to, was tested on board the "Nettle," on the 9th of December, 1891. The Holtzer projectiles fired at it were all stopped. One remained in the plate, the second rebounded and broke up, the third rebounded apparently uninjured. Two Palliser shells broke and stuck in the plate. There was not a single crack in the plate, either at the back or front, although small fissures and bulges were made behind the points of impact. On the 12th of January, 1892, three Holtzer forged-steel projectiles fired at the second plate, *Figs. 6*, were all broken, and their penetration was less than that attained in the December trials, though one of the Palliser chilled cast-iron shots caused a through-crack. The third plate, *Fig. 7*,¹ was tested on the 3rd of May, under precisely similar conditions, and stopped all the projectiles without slightest indication of cracking either at the back or front. The two Palliser shells as usual broke up, but in so doing they enlarged the holes to 8 inches in diameter. The back of the plate was bulged, but no fissure was made.

On the 1st of November, 1892, a solid steel plate, made by Messrs. Vickers, of Sheffield, and hardened by the Harvey process, was tested on board the "Nettle," at Portsmouth.

*Fig. 8*¹ is prepared from a photograph of the plate after being subjected to the same trial as those already referred to. The result is one of the best yet obtained. Another Harvey plate, *Fig. 9*¹, made of nickel steel by the Bethlehem Company, was tested on the 23rd July, 1892, at Indian Head, U.S. In this

Fig. 7.



FRONT.

¹ Reproduced from a photograph by the kind permission of the Editor of the *Engineer*.

trial, five 8-inch Holtzer forged-steel projectiles were used, each weighing 250 lbs., and having a velocity of 1,700 feet per second. Three of the projectiles broke after effecting slight penetration; the other two penetrated more deeply and rebounded, one of them causing a through-crack. This and the previous test show that great improvement has been made in the manufacture of the Harvey plate; but the difficulty referred to is experienced when

Fig. 8.



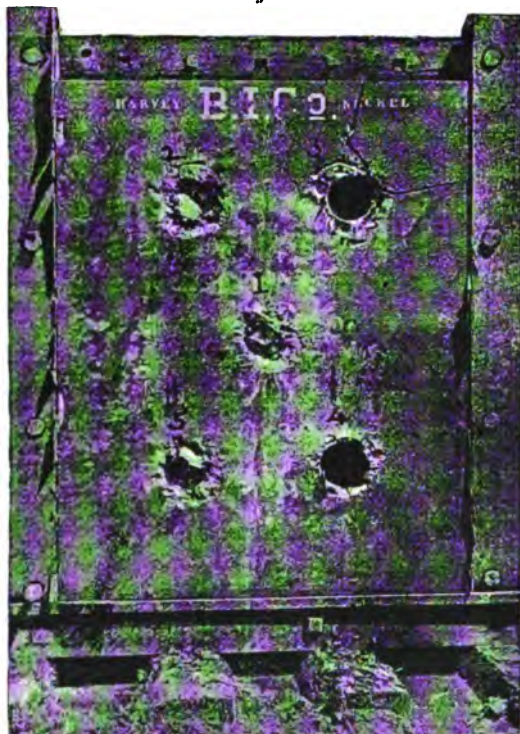
FRONT.

this process of hardening is applied to curved armour. In resisting chilled shot, or any inferior projectile, the plate is greatly racked in consequence of the wedge-like action produced by the shot. The holes made in the plate by these shots are usually from one-third to one-quarter larger than their diameter, whereas a modern forged-steel shot, which does not up-set, makes a hole equal to its diameter only. Owing to this racking effect, steel armour-plate of the finest quality is said to be broken and peeled

off a ship's side by the blows of inferior shot which may be quite unable to pierce it; while such projectiles produce scarcely any effect upon compound armour, as they are simply pulverised against its hard face, without being able to make any practical impression, the indentations being in most cases from 1 inch to $1\frac{1}{2}$ inch deep.

It will be readily understood that great difficulty is experienced

Fig. 9.



FRONT.

in estimating a plate's power of resistance, otherwise than by trial. If it be remembered that the total energy of a shot at the instant it strikes may be distributed in effecting its deformation or wreck, while it imparts to the plate a shock which affects the mass, probably accompanied with slight penetration, radial cracking, bulging at the rear, severing part of the backing, and racking the entire structure; the question may be asked, is it possible to ascertain how much energy has been spent on one

effect of the blow more than on any other? Repeated attempts have been made to formulate rules for the determination of armour-plate efficiency, but, as far as the writer is aware, the best formulas used in this or in foreign countries are either empirical or deduced from the energy expression $\frac{W V^2}{2g}$. The formulas generally employed in England at the present time for the determination of the power of resistance of armour-plate, are that of Fairbairn and that known as "Maitland's formula of 1880."

The former is

$$\frac{W V^2}{2g} = \pi D t^2 K,$$

and gives the energy of a shot in foot-tons at the striking instant.

By transposition,
$$t = v \sqrt{\frac{W}{2g\pi DK}},$$

where t is the thickness of the plate in inches,

W „ weight of shot as a fraction of a ton,

V „ velocity of shot at the striking-instant in feet per second,

D „ diameter of shot in inches,

and K „ a constant determined from experience,

"Maitland's formula of 1880," for all velocities over 700 feet per second, is

$$t = \frac{V}{608 \cdot 3} \sqrt{\frac{W}{D}} - 0 \cdot 14 D.$$

Captain Orde Brown has introduced a ready method for calculating the extreme thickness of iron plate which can be perforated by shot of ordinary figure, by the formula

$$t = \frac{V D}{1,000}.$$

This rule, says Captain Orde Brown, applies to projectiles in which $\frac{W}{D^3}$ approaches 0·4, fired with velocities less than 2,000 feet per second. If applied to projectiles of which the ratio $\frac{W}{D^3}$ is large, as in the 10-inch and 13·5-inch breech-loading guns,

where it reaches 0·5, or to velocities much exceeding 2,000 feet per second, a considerable error arises.

The Gâvre formula, commonly used in France, is

$$P V^2 = a 1600^2 t_1^{1.4},$$

where P is the weight of projectile in kilograms,

V „ velocity of projectile in metres,

a „ calibre of gun in decimetres,

and t_1 „ thickness of plate in decimetres.

This formula has been modified with good results by Mr. J. de Marre, thus :

$$P V^2 = \lambda a^{1.5} 1280^2 t_1^{1.3},$$

where the symbols have the same values as in the Gâvre formula, and λ is a function of the quality of both projectile and plate.

Although the English expressions give approximately the same results, they differ from the foreign formulas at velocities less than and exceeding 1,580 feet per second, as shown in the Table following, calculated for a 6-inch 100-lb. projectile.¹

Formula.	Perforation through wrought-iron, striking at		
	1,000 feet.	1,580 feet.	2,400 feet.
Fairbairn (English)	Inches. 5·92	Inches. 9·88	Inches. 15·26
Maitland „	5·87	9·72	15·26
J. de Marre (French)	5·01	10·13	19·25
Krupp (German)	4·94	9·82	18·39

The foreign formulas here employed are those communicated by Lieutenant Perry, U.S. Artillery, viz. :—

$$\text{De Marre's} \quad . \quad . \quad . \quad t^{0.65} = \frac{W^{\frac{1}{2}} V}{\log^{-1} \cdot 2 \cdot 9616 D^{\frac{1}{2}}};$$

$$\text{Krupp's} \quad . \quad . \quad . \quad t = \frac{W V^2}{\log^{-1} \cdot 5 \cdot 7776 D^{\frac{1}{2}}};$$

where t is the thickness of wrought-iron perforated, in inches,

W „ weight of projectile in lbs.,

V „ striking velocity in feet per second,

and D „ diameter or calibre in inches.

¹ The Author is indebted to Captain Orde Brown for these results.

With a view to test these formulas at high velocities, the Ordnance Committee, on the 20th July, 1892, fired a 6-inch Holtzer forged-steel projectile at a wrought-iron target 17 inches thick, with a striking-velocity of 2,378 feet per second. It would appear from the result, that Krupp's formula is the most accurate for high velocities. In this connection, it may be of interest to note a rough guide given by Captain Orde Brown,¹ as to the structural strength of projectiles and the limits to their possible perforation:

1. Common cast-iron shells will perforate and carry fire through a wrought-iron plate half a calibre thick. 2. Armour-piercing steel common and Palliser shells will perforate and carry fire through ordinary steel or steel-faced armour one calibre thick. 3. Forged-steel projectiles easily pass through wrought-iron plates two calibres thick.

In considering the resistance offered by armour-plates to projectiles carrying high explosives, it is found from experience that hard armour which breaks shells on impact, before they can penetrate deeply, is the most suitable for use in warfare.

The Paper is accompanied by photographs, from which the *Figs.* in the text have been prepared.

¹ "Armour and its Attack by Artillery," Supplement to Part II, p. 131.

OBITUARY.

JOSEPH BOURNE was born on the 5th of August, 1836, and commenced his engineering career at the early age of fifteen as a pupil in the Locomotive Works of the Great Western Railway Company at Swindon. After the expiration of his five years' apprenticeship he was occupied from 1854 to 1856 on the construction of the South Wales Railway, now part of the Great Western system. He was then engaged for two years as an Outdoor Locomotive Superintendent on the Great Western Railway, the service of which Company he resigned in 1858 to accept the post of manager to Messrs. Tredwell's Railway Works at Gloucester, since extinct. After remaining with that firm about three years, he was occupied from 1861 to 1864 as assistant manager at the Hednesford Colliery in Staffordshire.

In June, 1864, Mr. Bourne was appointed Resident Engineer, Locomotive Superintendent and General Manager of the Isle of Wight Railway, a line 12 miles in length from Ryde to Ventnor. The duties of that post, which he held for twenty-one years, may be said to have occupied the most important part of his life. On leaving the service of the Isle of Wight Railway Company in the summer of 1885, Mr. Bourne took up his residence at Stafford, where he remained for about three years. Between 1877 and 1883 he was lessee of the Britannia Works, Birkenhead, in which he carried on the business of the extinct firm of Messrs. James Taylor and Co. In the autumn of 1892 he left Birkenhead for Wylde Green in Warwickshire, where he died on the 2nd of July, 1893, in the fifty-seventh year of his age.

Mr. Bourne was a man of high honour and a marked sense of rectitude, and whatever work he undertook was conscientiously and carefully performed. He was elected an Associate of the Institution on the 6th of December, 1870, was subsequently placed in the class of Associate Member, and on the 6th of February, 1883, was transferred to the class of Member.

EDMUND COOPER, son of the late Mr. Robert Cooper of Scarning, Norfolk, was born there on the 1st of May, 1818, and was privately educated at Norwich. After serving a regular period of pupilage in the office of the late Mr. T'Anson, Surveyor to the Surrey and Kent Commissioners of Sewers, he entered in 1841 the service of that Commission as an Assistant Surveyor, and when in 1847 that body was consolidated with all other districts under the style of the Metropolitan Commission of Sewers, he was retained as a District Clerk of Works. Five years later he was selected by the Commissioners for the appointment of Engineer to one of the districts.

In 1856 the Commission of Sewers was merged into the newly created Metropolitan Board of Works and Mr. Cooper was appointed an Assistant Engineer under the late Sir Joseph Bazalgette.¹ The District entrusted to Mr. Cooper was the eastern portion, where some of the largest works connected with the Metropolitan Main Drainage² and with the Thames Embankment were carried out under his supervision. The cost of these works amounted to upwards of £2,000,000, and amongst them may be mentioned the following :—The Northern High-Level Sewer from Hampstead to Bow—The Northern Outfall Sewer from Bow to Barking Creek, a distance of 5½ miles, the largest contract let in connection with the main drainage. It was constructed entirely above the surface of the ground, and with eleven bridges over roads, railways, and river, was a difficult and complicated work to carry out—The Northern Reservoir at Barking built in the marshes and covering 10 acres of ground—The Northern Low-Level Sewer from Tower Hill to Abbey Mills, with the large pumping-station at the latter place—The Isle of Dogs branch of the Low-Level Sewer—The Victoria Embankment from Waterloo Bridge to Blackfriars Bridge, with the low-level main sewer and subway—and Queen Victoria Street with sewer and subway. In addition to these Mr. Cooper had under his charge the maintenance of the whole of the works of his district, amounting to about £12,000 per annum.

Owing to serious ill-health Mr. Cooper was obliged to retire from the service of the Metropolitan Board of Works in 1870. From that time he took no active part in the profession but lived quietly at Wallington in Surrey, interested in horticulture and

¹ Minutes of Proceedings Inst. C.E., vol. cv. p. 302.

² *Ibid*, vol. xxiv. p. 280.

farming pursuits. There he died, after a long illness, on the 22nd of June, 1893, at the ripe age of seventy-five. As to his ability as an engineer, no better testimony is needed than the opinion of his Chief, who, on Mr. Cooper's retirement from the Board of Works, spoke in the highest terms of the valuable services he had rendered on all occasions, and of the sound, substantial and enduring character of that portion of the works which had fallen to his share. One who acted under him for nearly thirty years writes as follows:—"Mr. Cooper was very kind-hearted towards all who had the good fortune to serve under him; very liberal and willing at all times to assist any person in need. I am able to say honestly that I never met a more noble-minded friend."

Mr. Cooper was elected a Member of the Institution on the 3rd of December, 1867.

EDWARD ALFRED COWPER, born on the 10th of December, 1819, was a son of the late Mr. Edward Cowper, professor in the engineering department of King's College, London, one of the early improvers of the printing-machine, and the Author of a Paper¹ on that subject read before the Institution in 1850. When only fourteen the subject of this notice was apprenticed for seven years to the late Mr. John Braithwaite.² While still an apprentice, he invented, about 1841 the detonating fog-signal, which was recommended as worthy of adoption by General Pasley, then Inspector-General of Railways, in a report dated the 14th of April, 1844.³ It was first tried on the Croydon railway, and has long since been in general use.

In 1841 Mr. Cowper entered the service of Messrs. Fox (afterwards Sir Charles Fox)⁴ and Henderson of Birmingham. While with that firm he invented an ingenious method of casting railway-chairs,⁵ and designed the wrought-iron roof of the New Street Station at Birmingham,⁶ which had a span of 211 feet—at that time the largest iron roof in existence. It was originally intended to have two spans, or more, supported by columns; but

¹ Minutes of Proceedings Inst. C.E., vol. ix. p. 409.

² *Ibid.*, vol. xxxi. p. 207.

³ *Ibid.*, vol. xxxviii. p. 204.

⁴ *Ibid.*, vol. xxxix. p. 264.

⁵ Proceedings Inst. Mech. Engs., 1851.

⁶ Minutes of Proceedings Inst. C.E., vol. xiv. p. 251, and Proceedings Inst. Mech. Engs., 1854, p. 79.

at Mr. Cowper's suggestion, that method of construction was not adopted. The site was extremely awkward, as it was formed of a parallel and two taper portions, on which were four platforms and ten lines of rails. The ground, however, was so surrounded by buildings that it was possible to adopt a sloping ridge over the taper portions and thus simplify the task of designing the principals, all of which were made similar, the dimensions of each part being reduced as the span narrowed. He also superintended the preparation of the contract drawings for the building of the Great Exhibition of 1851, which was subsequently re-erected at Sydenham for the Crystal Palace Company.

At the end of 1851 Mr. Cowper resigned his post as chief draughtsman and designer to Messrs. Fox and Henderson and commenced to practise on his own account in London as a consulting engineer. Six years later he invented the regenerative hot-blast stove, in which fire-bricks are used instead of the cast-iron pipes through which the air to be heated previously passed. He subsequently effected various improvements in this design, an account¹ of which he presented to the Institution in 1870; for that Paper he was awarded a Watt medal and a Telford premium. In its latest form, the stove consists of a vertical combustion-chamber, and a "regenerator" composed of a number of honeycomb passages or flues. Gas from the top of the blast-furnace is admitted to the combustion-chamber, together with air, and burns in it, the products of combustion, on arriving at the summit of the chamber, being drawn down through the honeycomb flues. The upper end of the regenerator rapidly becomes red-hot, and the heat travels gradually downwards until a considerable length of the flues becomes incandescent. The gas is then shut off, and blast is passed through the regenerator from the bottom to the top, gradually cooling it, the process taking some hours before the gas must be again admitted.

Mr. Cowper gave great attention to the subject of the economy of steam and was an ardent advocate of the compound-engine and of steam-jacketing. About the year 1858 he introduced the steam-jacketed receiver, which was subsequently known in the navy as "Cowper's Hot-Pot." In its early form, this was a vessel into which the steam entered at one end, leaving it at the other; but it was afterwards modified by the addition of an inner lining which forced every particle of steam in progress to the outlet to pass close to the heated walls.

¹ Minutes of Proceedings Inst. C.E., vol. xxx. p. 309.

At his suggestion, the engine-cranks were placed at right-angles, obviating the necessity of having six cylinders, two to each engine. In 1870 H.M.Ss. "Briton" and "Thetis" were fitted by Messrs. Rennie on this plan, with the result that the "Briton," when steaming at a speed of ten knots, burned only 1·3 lb. of coal per HP. per hour.¹

In 1879 Mr. Cowper invented a beautiful and ingenious instrument, the writing-telegraph,² by means of which the operator at a distant station was enabled to write as though he were present, without the use of any special signals, code or signs, and without the assistance of any person to translate the signals as received. The exact position of the pencil of the operator at the sending-station was communicated to the writing-pen at the receiving-station through two line wires, one giving the vertical and the other the horizontal position of the pencil. It may also be interesting to record that as far back as 1868 he designed what was practically the modern bicycle wheel—a wire-spoke suspension wheel with a rubber tyre. Other matters prevented him, however, from taking out a patent and the idea eventually became common property. In conjunction with Dr. Anderson, he carried out in 1887 a series of experiments on the mechanical equivalent of heat, the results of which were contained in a Paper³ read at the meeting of the British Association at Manchester in that year.

Another point which stands out clearly in Mr. Cowper's career is the part he took in founding the Institution of Mechanical Engineers. He was one of the few original members of that body at its inception in 1847 and in the following year was elected a Member of Council. In 1880-81 he served the office of President. Among the Papers he contributed to the Proceedings of that Institution may be mentioned, in addition to those already referred to:—"An Inverted Arch Suspension Bridge" (1847); "Cugnot's Locomotive for Use on Common Roads" (1853); "Blast Engines for the East Indian Iron Company" (1855); "Two Pairs of Horizontal Pumping Engines" (1858); "Regenerative Hot-Blast Stoves working at a temperature of 1,300° Fahrenheit" (1860); and "The Inventions of James Watt, and his Models preserved at Handsworth and South Kensington" (1883).

Mr. Cowper was a member of the Committee of Advice with reference to the collection of models in the Machinery and Inven-

¹ Minutes of Proceedings Inst. C.E., vol. li. p. 62.

² Journal of the Society of Telegraph Engineers, vol. viii. p. 141.

³ Report of the British Association, 1887, p. 562.

tions Division of the South Kensington Museum, an exhaustive catalogue¹ of which, prepared by him, was published by the Science and Art Department in 1890. He was a member of the Jury at the International Inventions Exhibition and acted as a judge for the Royal Agricultural Society in 1868 and 1870. Among his many miscellaneous inventions may be mentioned improvements in candle-making machinery adopted by Price's Candle Company; an apparatus for the recovery of lead fumes which effected great economy by securing fine particles of lead previously lost through the chimney; a sugar-cutting machine in which knives arranged in squares were employed to cut the slab into small cube-shaped lumps; and an improved gin for removing the fibre of cotton from the seed. He frequently acted as a witness in patent and arbitration cases.

Mr. Cowper was elected an Associate of the Institution on the 13th of January, 1852, and was transferred to the class of Member on the 28th of February, 1860. In 1878 he was elected a Member of the Council, on which he continued to serve until his death. In addition to the Paper on the "Regenerative Hot-blast Stove," above referred to, he delivered before the Institution on the 17th of January, 1884, a lecture on the "Steam-Engine," which formed one of the special series of lectures on "Heat in its Mechanical Applications." He was a constant attendant at the meetings and frequently took part in discussions; shortly before his death he interested himself greatly in a Paper on the "Break-down of the R.M.S. 'Umbria,'" by Mr. Thomas Sopwith, and it was under his direction that the model of the broken shaft of that vessel, then exhibited, was prepared.

Mr. Cowper died from pneumonia, after a very brief illness, on the 9th of May, 1893, at the age of seventy-three. He may be said to have died in harness, for it was only a few weeks previously that he had taken into partnership his son, Mr. Charles E. Cowper, with a view of relieving himself from much of the strain of work which he had begun to feel.

FRANCIS FOWLER, fifth son of the late Mr. J. K. Fowler of Aylesbury, was born on the 28th of June, 1829, and in March, 1846, was articled for three years to the late Mr. Richard Madigan, then an engineer on the London and Birmingham Railway. On

¹ Library Inst. C.E.

the expiration of his pupillage he remained with that gentleman as an assistant for about six months and afterwards was employed by the late Mr. Isaac Dodds¹ to assist in the design of locomotives and rolling-stock for the Santander and Alar Railway in Spain. In November, 1853, he proceeded to Canada, where he was appointed Resident Engineer in charge of the construction of 12 miles of the Montreal and Bytown Railway. He opened, and for a time superintended, the working of that section, but owing to financial difficulties the construction of the line was then temporarily abandoned.

Returning to England in November, 1855, Mr. Fowler was employed for a time in making designs for large river bridges for the Bombay and Baroda Railway. In September of the following year he proceeded to India to take up the appointment of District Engineer on the Umritsur Division of the Punjab Railway, 32 miles in length and including large terminal stations at Lahore and Umritsur. That division was the first portion of a railway constructed in Northern India, and upon Mr. Fowler devolved the troublesome task of training the unskilled natives in the various branches of work they had to perform. He held that post until February, 1861, when he returned to England. On the recommendation of the late Sir W. P. Andrew, then Chairman of the Punjab Railway Company, he was appointed in May, 1862, Chief Engineer to the Hindostan (Singhoom) Copper Company and again proceeded to India. He had the entire management of the mines and works in India and the control of the expenditure of the company, in addition to which he had to open up the approaches to the mines by making roads and building bridges in a wild and inaccessible country. All these duties he carried out to the satisfaction of the directors; but after two years' arduous work and constant exposure to the climate his health broke down; he was obliged to resign his appointment and return to England.

While in India Mr. Fowler had saved some money which he was now unfortunately induced to invest in the Railway Finance Company, an undertaking established to facilitate and promote the construction of railways and other public works. For a time he acted as engineer to that company, but it soon proved to be an unprofitable enterprise, and by its failure he lost all he possessed. He then determined to abandon railway work and from that time devoted himself almost entirely to inspecting and reporting upon

¹ Minutes of Proceedings Inst. C.E., vol. lxxv. p. 308.

mining projects in various parts of the world, in some cases undertaking also the management of the mines. He was largely instrumental in exposing the worthlessness of the gold mines in the Wynaad.

After reporting on gold-fields in India, New South Wales, and South Africa, Mr. Fowler was appointed, in 1871, Engineer to the Mammoth Copperopolis Company's mines in Utah, and for the next three years resided at Salt Lake City. During that time he was also connected with the Saturn Silver Mining Company in Utah and with the Phoenix Quicksilver Mining Company, in California. On leaving the service of the Mammoth Copperopolis Company he returned to England; after a time he proceeded to South America to report on Mining projects in the Andes and subsequently visited Mexico, California and Newfoundland with the same object. But the effects of an attack of jungle-fever, contracted during his first visit to India, told heavily upon him during these arduous and sometimes dangerous ventures, and occasionally he was compelled to abandon work and rest for a time. These periods of enforced idleness were a serious drain upon his resources, but at length a prospect opened up which promised great things. During one of his visits to the South of France he had reported very favourably on a valuable manganese mine, and was about to proceed to that country to take charge of its working when he was unfortunately struck down by a severe attack of dysentery, which ended fatally on the 9th of February, 1893.

Little more than an indication of Mr. Fowler's eventful career has been here given, but in the absence of any private record it has not been possible to obtain particulars of the numerous ventures in which he was interested during the last thirty years of his life. He was elected a Member of the Institution on the 6th of February, 1866.

HENRY GILL, born at Rye in Sussex on the 10th of March, 1824, was educated at private schools and subsequently at the defunct College for Civil Engineers, Putney. His first professional employment was in connection with land and harbour surveying, in which he was engaged for about two years. He then became an Assistant-Engineer on the construction of the Great Northern Railway and so efficiently did he perform his duties during the five years he held that post that the Consulting Engineer of the

line, Sir William Cubitt,¹ who was also Engineer to an English Company for the supply of water to Berlin, entrusted him in 1853 with the carrying out of the works in that city.

Mr. Gill's connection with the Berlin Waterworks was destined to last for the remainder of his life—a period of forty years. When he entered upon his duties in 1853 his knowledge of the German language and people was slight, but so satisfactorily did he complete his task, frequently under delicate and difficult circumstances, that three years later he was appointed Engineer and manager of the new works. In 1873 the City Council determined to purchase the works from the company. The first step the authorities took, on the completion of the purchase, was to appoint Mr. Gill Engineer-in-Chief and to instruct him to make a full report to the City Council on the present and future prospects of the water-supply of Berlin. He advised that the Lake of Tegel, lying to the north-west of the city, should be the future source of supply.

The works purchased in 1873 lay to the east of the city and supplied only the heart of the town, as they were not capable of delivering more than 13,200,000 gallons per day. In the following year Mr. Gill submitted to the municipality designs for new works, to the north-west of the city at Tegel, capable of delivering 19,140,000 gallons per day. The scheme was approved and one half of it was completed and put in action in 1877, the remaining half, with the corresponding extensions of the mains in the city, being opened in 1885.² The population, however, continued to increase so rapidly that in 1887 Mr. Gill advised the Council to look for a further source of supply, for which he proposed the Mueggel-See, a large lake to the east of Berlin, which he estimated would suffice for a population of about 2,500,000, a million more than it then was. New works were taken in hand in 1890 and Mr. Gill had hoped to see their completion. Although his health was giving way he remained at his post and pushed the works forward with great energy. His desire, however, was not destined to be fulfilled, for after a short but painful illness, he died on the 17th of June, 1893, the day on which it was intended to commence the works necessary for the completion of the final scheme.

In addition to his official duties at Berlin, Mr. Gill was frequently consulted as to the water-supply of other towns and was recognized on the Continent as a great authority in that branch of engineering.

¹ Minutes of Proceedings Inst. C.E., vol. xxi. p. 554.

² *Ibid.*, vol. cvii. p. 210.

For forty years, during which the population increased from 500,000 to 1,750,000, he directed the waterworks of Berlin and at all times furnished the city with a plentiful supply of pure water. As some recognition of his services, a movement is now on foot in Germany to erect a bronze bust (larger than life size) of him at the new works at the Mueggel-See. To his staff and to all who came in contact with him, he endeared himself greatly by his strong sense of justice, his disinterestedness and never failing kindness.

Mr. Gill was elected a Member of the Institution on the 4th of December, 1860. In 1891 he presented a Paper¹ on "The Sale of Water by Meter," which system had been adopted at Berlin in May, 1878. It elicited a useful and interesting discussion and obtained for the Author a Telford Premium.

WILLIAM MAGEE GRIER the third son of the late Rev. John William Grier, M.A., Incumbent of Amblecote, near Stourbridge; nephew of the late Archbishop Magee of Dublin and cousin of the late Archbishop Magee of York, was born on the 17th of September, 1839. At sixteen years of age he was articled to Messrs. Cochrane Brothers of Woodside, near Dudley. During the five years of his pupilage he was occupied in the workshops and in the drawing and estimating offices and was subsequently employed by Messrs. Cochrane to assist in the erection of the Westminster and Charing Cross Bridges over the Thames. He was next engaged for Messrs. Ordish and Le Feuvre in preparing designs and details for the Exhibition buildings of 1862 and then for Mr. Henry Carr on designs and working drawings for the Blackfriars Railway Bridge. In 1863 he inspected bridges for the Concessionaires of certain Italian railways and was then for two years Engineer to Messrs. Fleet and Newey, bridge builders in Staffordshire. In 1865 he became an assistant to Mr. W. H. Barlow, Past-President Inst. C.E., on the Midland Railway extension to London. He prepared detail drawings of bridges and other works at the London end and superintended their construction; and was also placed in charge of the erection of a portion of the roof of the station at St. Pancras,² and of the columns and girders of the lower floor.

¹ Minutes of Proceedings Inst. C.E., vol. cvii. p. 203.

² *Ibid*, vol. xxx. p. 78.

Mr. Grier then became in 1869 Engineer to the Park Gate Iron Company, Rotherham, which had large contracts in hand for bridges and roofs; on the completion of some exceptionally difficult iron-roof and girder work for Messrs. John Aird and Sons at the Chartered Gas Works, Beckton, he retired from that post. In 1870-71 he was employed by the late Mr. J. M. Heppel,¹ Consulting Engineer to the Oude and Rohilkund Railway Company, in preparing the plans and detail drawings of large workshops and running-engine sheds for Lucknow; on the completion of these, contracts were let and the materials sent forward and set up, Mr. Grier being requested to proceed to Lucknow and superintend the erection, a request to which he was unable to accede. In 1872 he became General Manager and Engineer to the Trent Foundry Company, which post he held for five years.

On the nomination of Mr. (now Sir) Charles Hutton Gregory, K.C.M.G., Mr. Grier was appointed in 1877 an Engineering Assistant in the Public Works Department of Cape Colony. Four years later the post of Chief Inspector of Public Works became vacant and in 1882, on the expiration of one year's probation, Mr. Grier was permanently appointed to it. His duties included the construction and maintenance of new roads, bridges and public buildings; the charge of all the lighthouses along the coast, and of the East London and Port Alfred Harbours, at the former of which very difficult and heavy works were under construction. During Mr. Grier's tenure of office the works carried out by the department increased rapidly both in number and magnitude. The new Houses of Parliament in Cape Town and several important buildings at Port Elizabeth, Kimberley and other parts of the Colony, were erected. Some heavy mountain roads were formed and numerous bridges were erected, amongst them being the cantilever bridge over the Gouritz River, the largest bridge in South Africa. Mr. Grier was a member of the Meteorological Commission and of the Philosophical Society, a Road Magistrate for the Colony and a Justice of the Peace.

For some time past Mr. Grier had been afflicted with cancer in the throat, a most distressing malady, and in the winter of 1892-93 he came to England for special treatment. One physician took a somewhat hopeful view of the case and for a time it was thought that he would recover sufficiently to resume control of his Department. This confidence, however, was short lived; before Mr. Grier left England he knew he was returning

¹ Minutes of Proceedings Inst. C.E., vol. xxxvi. p. 265.

to South Africa to die; and after a long period of suffering and gradual exhaustion, he passed away at Wynberg on the 26th of May, 1893, at the comparatively early age of fifty-four.

Mr. Grier was greatly respected throughout the Colony, not only for the able and conscientious performance of his professional duties, but for the keen sense of justice and kindly feeling he displayed towards all with whom he was brought into contact. He was strongly interested and rendered constant assistance in Church matters. The calm fortitude and patience with which he bore the terrible sufferings of his last illness have been characterized as truly wonderful. He was elected a Member of the Institution on the 6th of March, 1883.

JOHN HEAD was born in Birmingham on the 11th April, 1839, and was educated in France. On leaving school he was engaged in that country as a bank clerk until his nineteenth year, when he returned to England and set up on his own account as a commission agent. He carried on a successful business in steam-gauges and other engine-fittings, and it was probably in connection with the sale of these that he first became acquainted with Mr. (afterwards Sir) William Siemens,¹ who was then agent for the Berlin firm of Siemens and Halske. In 1859 Mr. Head was engaged by Messrs. Siemens and Halske and in the following year was appointed personal assistant to Mr. William Siemens, who had a private engineering business. From that time he devoted himself absolutely to the work and interests of his employer, and if there is little or nothing to chronicle specially about him, it is because he sank his own personality entirely in that of Mr. Siemens. In 1868 Mr. Head took special charge of the furnace and metallurgical business, which some years later, and until William Siemens's death, he managed, as principal assistant. On the transfer of the business to Mr. Frederick Siemens—after the death of Sir William—Mr. Head was appointed general representative of the firm for England, France, Belgium, Spain, Portugal, the United States of America, and the Colonies and Dependencies of those countries. During the whole of his career he was actively engaged in this country and abroad in superintending the design, construction, and working of regenerative gas-furnaces applied to

¹ Minutes of Proceedings Inst. C.E., vol. lxxvii. p. 352.

various industries and especially to the manufacture of iron, steel and glass.

In the beginning of 1885 Mr. Head brought before the South Staffordshire Institute of Iron- and Steel-Works managers Mr. Frederick Siemens' system of heating by radiation. According to this system the heat resulting from combustion is utilized in two stages; in the first, when the heat is developed, free space is allowed so as to prevent the flame from coming into contact with solid substances, which disturb combustion and, being generally at a lower temperature than the flame, produce smoke. In the second stage, intimate contact takes place between the products of combustion and the regenerators of the furnace in which the heat is preserved for future use. In 1887 he read at the Sanitary Congress at Bolton a Paper¹ on the application of heating by radiation to Gas-Fired Steam-Boilers. Two years previously he had brought before the Iron and Steel Institute an invention of his own under the title of "A Modified Form of the Siemens' Old Type Gas-Producer; by means of which the Gases are enriched, and the by-products may be recovered."² In this arrangement the gas-producer is divided into two compartments, one to receive the hydro-carbons, the volatile constituents of the coal, and the other the carbonic oxide formed by the decomposition of solid carbonaceous matter, by means of a curtain-wall to separate the zone where the hydro-carbons are produced from that where carbonic oxide is formed. In the following year he presented to the same Institute a Paper³ on "Blow-Holes in Open-Hearth Steel," in which he brought forward evidence to show that blow-holes and seedy boil were found in steel and glass melted by contact of the flame with the material treated, but were absent when heating by radiation of the flame was adopted.

In 1889 he read, in conjunction with Mr. Pouff, who at that time represented Mr. Frederick Siemens in Paris, a Paper, at a meeting of the Iron and Steel Institute,⁴ on "A New Form of Siemens' Furnace arranged to Recover Waste Gases as well as Waste Heat," which was discussed in 1890. According to this arrangement, which is the invention of Mr. E. Biedermann, and Mr. E. W. Harvey, both on the technical staff of Mr. Frederick Siemens, a certain proportion of the waste products of combustion is supplied hot into the incandescent fuel of the gas-producer, and the carbonic

¹ Trans. Sanitary Institute of Great Britain, vol. ix. p. 336.

² Journal Iron and Steel Institute, 1885, p. 126.

³ *Ibid*, 1886, p. 99.

⁴ *Ibid*, 1889, p. 256, and 1890, p. 18.

acid contained in the waste products is thus converted into carbonic oxide, by which a considerable economy in fuel is realized. This necessitates having the gas-producer close to the furnace, which gas-producer further takes the place of the gas-regenerator in the original form of Siemens furnace, so that in the new form of Siemens furnace the gas-regenerators are suppressed, and the construction of the furnace simplified.

In 1886 Mr. Head was requested to read a Paper¹ on the "Manufacture of Glass and Steel on the Open-Hearth" before the Mechanical Section of the British Association at its Birmingham Meeting, and shortly before his death he presented to the Iron and Steel Institute "Some Notes on Puddling." For many years he had not been in the enjoyment of robust health; and he succumbed to an attack of pneumonia, after only six days' illness on the 14th July, 1893. Mr. Head was a Fellow of the Geological Society and was elected a Member of this Institution on the 5th of February, 1889.

FREDERICK MARGARSON HYNES was born on the 23rd of February, 1842. After serving a regular period of pupilage in the office of the late Mr. James John Berkley,² Chief Engineer in India to the Great Indian Peninsula Railway, he remained in the service of that Company as an Assistant Engineer, which post he held for six years. He was then promoted to Resident Engineer and placed in charge of a section of the line. During the two years he occupied that position the whole of the section was doubled, an undertaking which involved some important constructional works, as well as the maintenance of the existing line.

In July, 1873, Mr. Hynes retired from the service of the Great Indian Peninsula Railway Company and entered the Public Works Department of Victoria as an engineering and architectural draughtsman. After being engaged in that capacity for nearly five years he was appointed in January, 1878, Engineer in charge of the harbour, coast and river works of the colony. This post involved the design and execution of numerous works of importance, including lighthouses, piers, breakwaters and bridges. In August, 1890, at the recommendation of the Chief of the Department, the Office of Roads and Bridges was amalgamated

¹ Report British Association, 1886, p. 800.

² Minutes of Proceedings Inst. C.E., vol. xxii. p. 618.

with that of Harbours and Rivers and placed under the control of Mr. Hynes. He was not destined, however, to hold this important position long, for he died on the 1st of January, 1892, at the comparatively early age of fifty.

Mr. Hynes was greatly esteemed in the Department of Public Works, not only for his engineering ability but also for his integrity of purpose and kindly disposition. He was elected a Member of the Institution on the 13th of January, 1891.

DANIEL MACNEE, eldest surviving son of the late Sir Daniel Macnee, President of the Royal Scottish Academy, was born on the 23rd of April, 1838. After being educated at Glasgow and in Dumfriesshire, he served an apprenticeship of five years to Messrs. Smith and Rodger of Glasgow (now the London and Glasgow Engineering and Shipbuilding Company). Before completing his pupilage he attracted the notice of the late Mr. Edward Wilson, then Engineer to the West Midland Railway (since amalgamated with the Great Western Railway), who made an opening for him on the staff of that line. He was articled to Mr. Wilson in 1858 and was engaged on the construction of the railway between Honeybourne and Stratford-on-Avon. In 1862 he was appointed Resident Engineer and District Superintendent of the Newport, Abergavenny and Hereford section, or South Wales Division, of the West Midland Railway. During the time he held that post he completed the Taff Vale extension to Mountain Ash and constructed several branches.

In 1866 Mr. Macnee left the service of the West Midland Railway Company to take up the appointment of Engineer to Messrs. Charles Cammell and Company, for which firm he erected new works at Penistone and Grimesthorpe. Three years later he resigned this post and became a junior partner in the firm of Joseph Armstrong and Company of Rotherham, manufacturers of railway-points, crossings and other permanent-way material. In the previous year, at the request of the Royal Commission on Irish railways, he valued and reported upon the whole of the workshops, machinery, engines and rolling-stock of all the companies south of Dublin.

Mr. Macnee's connection with the firm of Joseph Armstrong and Company lasted until 1877, when he set up in practice on his own account as a Civil Engineer and contractor, at first in Rotherham

and subsequently in Westminster. He made surveys for and designed and erected the wagon shops at Sandy Acre, near Trent. He acted as London representative for the Auderston Foundry Company during the last fifteen years of his life.

Towards the end of 1892 Mr. Macnee was attacked by dropsy, which was soon followed by other serious complications. He was unable to recover his strength and after six months' illness passed away on the 30th of June, 1893. In his professional life he was energetic and zealous, which qualities, combined with a generous disposition and a pleasant manner, made him greatly esteemed by all with whom he came into contact. He was elected a Member of the Institution on the 11th of January, 1887.

JOHN MACRAE, son of the late Mr. William Macrae of Carra-dale, Argyllshire, was born on the 4th of July, 1836. In 1854 he was apprenticed for five years to Mr. Ronald Johnstone, Civil and Mining Engineer, of Glasgow. Soon after the expiration of his pupillage he became, in 1860, principal assistant to Mr. John Miller, jun., of Edinburgh, for whom he staked out and prepared the working plans and sections for the Dumfries and Lockerby Railway. In 1864 he was appointed chief agent to Mr. William Aiton in connection with a contract that gentleman had undertaken for the execution of 40 miles of the Suez Canal. In the following year, however, Mr. Aiton relinquished the contract and Mr. Macrae again became principal assistant to Mr. Miller, for whom he then staked out and prepared the working plans and sections of the Girvan and Port Patrick Railway.

Mr. Macrae continued to act in this capacity until 1869 when he commenced to practise on his own account in Edinburgh. Among his first employers was the late Sir Thomas Bouch,¹ for whom he prepared the Parliamentary plans for the projected Glasgow Tramways. The year 1870 was spent in surveying in the North of England in connection with railway projects and in preparing the Parliamentary plans for the Edinburgh and Dundee Tramways. In the following year Mr. Macrae was appointed Engineer to the Edinburgh Street Tramways Company, which post he held until July, 1884. The Act authorizing the incorporation of the Company and the construction of certain tramways was passed in

¹ Minutes of Proceedings Inst. C.E., vol. lxiii. p. 301.

June, 1871, and as soon as the necessary capital had been subscribed the works were commenced, and the first section—from the Haymarket to Waterloo Place—was opened for public traffic in the following November. In the same month the St. Andrew Square loop was completed and in 1872 the General Post Office to Powburn and the Grange and Morningside sections were opened. All the tramways authorized by the Act of 1871 were constructed on the old system of flat-iron rails bolted on to longitudinal wooden sleepers. It was very soon discovered, however, that a combination of timber and iron or steel in any form was unsuitable for a street-tramway, owing to the great difficulty and expense of maintaining for any length of time the fastenings securing the rails to the sleepers.

As the result of experiments Mr. Macrae satisfied himself that if a rail could be manufactured in the form of a girder, with a groove in the top of it, this difficulty could be overcome. After many trials the Barrow Hematite Steel Company undertook to roll rails to a section 8 inches in depth, 7 inches in width of flange or sole, and with a head 3 inches in width having a groove for the flange of the car-wheels planed out of it. Steel rails of this section were laid down in Princes Street, Edinburgh, in 1878, and towards the end of the year Mr. Macrae laid down in Princes Street a number of chilled blocks with corrugated surface, placed alternately with stone or wood blocks adjoining the rail. This experiment proved successful and the whole of the lines were subsequently laid with these blocks. In 1882 and 1883 various extensions were constructed, bringing up the total length of tramways in Edinburgh to nearly 12 miles.

Between 1873 and 1877 Mr. Macrae acted as Engineer-in-Chief on the construction of the Girvan and Port Patrick Railway, for which he had some years previously prepared the working plans and sections. In 1880 he was employed by the Corporation of Edinburgh in connection with the construction of the Suburban Railway and obtained from the Railway Company concessions which were deemed necessary in the interests of the city. About this time also the Commissioners of the Police of Portobello sought his advice in regard to the sanitary arrangements of new dwellings within that burgh and as to the construction of streets and sewers. Mr. Macrae was also Engineer to the Paisley, the Greenock and Port Glasgow, and the Rothesay Tramways Companies; and to the Kirkcaldy and District, and the East of Fife Central Railway Companies. He thus acquired considerable experience in the construction of tramways and railways and his

services were retained in most of the important arbitration cases in Scotland arising during late years out of such enterprises.

Until within a fortnight of his death Mr. Macrae enjoyed excellent health. An affection of the heart, however, then showed itself and, unforeseen complications supervening, his illness terminated fatally on the 12th of July, 1893. Of a quiet and retiring disposition, although genial and kindhearted, Mr. Macrae was esteemed and respected by all who knew him. He was elected a Member of the Institution on the 7th of February, 1882.

RICHARD OSWALD ROBSON, son of the late Mr. Robert Robson, agent to the then Lord Eglinton, was born in Ayrshire on the 21st of July, 1826. In 1841 he was articled for seven years to his brother, the late Mr. Niel Robson,¹ who was practising in Glasgow as a Civil and Mining Engineer. During that time he was employed on general, field and office work, and on a project for the water-supply of Glasgow by gravitation from a large reservoir in the valley of the Avon at Gilmerston, about 24 miles south of that city.² After the expiration of his pupillage he was engaged for some two years on surveys and railway work in Scotland.

In 1850 Mr. Robson emigrated to Victoria and, after spending some time at the gold-fields, entered the Railway Department of that colony, in which he remained until 1864, serving during that time under the late Mr. Thomas Higinbotham³ and the late Mr. Robert Watson,⁴ and being employed on every description of work connected with the construction of railways from the first preliminary surveys to the final completion. From 1864 to 1868 he was in the service of the Victorian Mining and Water-Supply Department, where he discharged his duties in a most satisfactory manner.

About the year 1873 Mr. Robson was sent by the Government of Victoria to Stawell, in the north-western district of that colony, as Quantity Surveyor, which post he held until his decease. He was allowed to undertake work on his own account and soon formed an extensive practice as an engineer and surveyor, being largely employed by the Shire Councils and by various Water

¹ Minutes of Proceedings Inst. C.E., vol. xxx. p. 456.

² *Ibid.*, vol. xxxvi. p. 257.

³ *Ibid.*, vol. lxiii. p. 314.

⁴ *Ibid.*, vol. civ. p. 304.

Trusts and other public bodies. For a brief period he held the post of Engineer to the Shire of Stawell, which, however, press of private business obliged him to resign. Soon after coming into the district he took up land between Stawell West and the foot of the Black Range, part of which he cultivated in addition to his professional duties. While driving through one of his paddocks he fell from the vehicle, the wheels passing over him and causing two compound fractures of the left leg and other serious injuries. He was taken to the private ward of the local hospital, but from the first the case was looked upon as desperate and he expired after great suffering on the 28th of March, 1893.

Mr. Robson's professional work was always carried out with great accuracy and conscientiousness. Of a retiring disposition, even his most intimate friends knew little of his history; he was, however, widely known and respected throughout the colony. Mr. Robson was elected a Member of the Institution on the 4th of December, 1888.

WILLIAM WISEMAN was born on the 26th of January, 1843, at Grassington, a village 9 miles from Skipton in Yorkshire. He received his early education in the village school, and subsequently, when his parents removed to Bradford, at the Old Parish Church National School in that town. There he showed great ability in mathematics and in freehand and architectural drawing, which was further developed by personal and private effort during his first situation in the office of the late Mr. Woodcock, Land Surveyor, Bradford. In 1863 he enlisted in the Corps of Royal Engineers, and, passing through the Indian branch of the School of Military Engineering, Chatham, with great credit, he proceeded as a sergeant to India. There he went through the course of training for a subordinate at the Thomason Civil Engineering College, Roorkee, and, being a neat draughtsman in the sense of being able to copy and colour drawings, he caught the eye of the late Major-General Medley, R.E.,¹ then Principal of the College, with the result that, on passing for the rank of overseer, instead of being sent out on works, he was posted Assistant Drawing Master to the College. Being an extremely well-spoken and well-behaved man, with a fair education and a distinct talent as a musician, he was popular and, the Public Works Department having at that time great difficulty in obtaining Assistant

¹ Minutes of Proceedings Inst. C.E., vol. lxxx. p. 343.

Engineers, he and other promising men who had gone in for the subordinate class were transferred, pushed through the officer class and appointed Apprentice Engineers. It was in December, 1869, that this good fortune happened to young Wiseman. He was posted to the Railway Branch and was employed for more than eight years on the Indus Valley State Railway, on surveying, designing and construction. From time to time he was in independent charge of divisional works as Officiating Executive Engineer, the principal of these being the construction of the line through the Lakhi Pass, formed through the mountains of that name in the Karachi District of the province of Sind.

After eighteen months' furlough in England Mr. Wiseman returned to India in October, 1879, and for the next three years was in independent charge of works on the Bhopal State Railway, the Sindia-Neemuch Railway, the Neemuch-Nasirabad Railway and the Eastern Deccan Railway, being promoted to Executive Engineer, 4th-Grade, in January, 1880, and to 3rd-Grade in the following June. In September and November, 1882, he was on sick leave and then acted for a short time as Personal Assistant to the Engineer-in-Chief of the Southern Mahratta State Railways. From December, 1882, to the corresponding month in 1883, Mr. Wiseman was on furlough. On his return to work he was appointed Assistant to the Director-General of Railways and in October, 1884, was placed in charge of a division of the Sind-Peshin State Railway. In the following December he was obliged to take twelve months' leave on medical certificate.

Having been promoted to Executive Engineer, 2nd-Grade, in January, 1885, Mr. Wiseman was, on his return to India at the beginning of the following year, placed in charge of a division of the Sind-Sagar State Railway. In March, 1887, he was transferred to the Tounghoo-Mandalay Railway, on which he remained for eighteen months, when he was again forced to take a year's sick leave. In November, 1889, being once more able to resume work, Mr. Wiseman was posted to the Hyderabad-Umarkot Railway Survey and in the following February was transferred to the Frontier Railway Survey. In December, 1890, he was promoted to Executive Engineer, 1st-Grade, and then took twelve months' furlough, six of which were without pay. On his return to India in December, 1891, Mr. Wiseman was posted to the Mari-Attock Extension Railway and to the Frontier Railway Survey, on both of which works he acted as Engineer-in-Chief during the month of August of the following year.

His health, however, which for some time had been indifferent, now became seriously impaired and he died at Dera Ismail Khan, from malignant disease of the liver, on the 16th of March, 1893, at the comparatively early age of fifty. A correspondent writes of him as follows :—

“I have seldom known a more kindly, gentle and industrious man. His instincts were clerical rather than practical, but he gradually acquired sufficient technical experience to carry on ordinary construction work. Aided by the strong personal good-will of certain highly-placed Royal Engineer officers, he was for some years employed as personal assistant to various chiefs and acquired the official style of issuing written orders and compiling statistical returns, both at Simla and on various construction jobs. He also held, not unsuccessfully, various divisional charges, and, as far as his wretched health allowed, was an experienced and hard-working surveyor. There is no doubt that the hope of being specially selected for high office—a hope for which there was hardly sufficient warrant in fact—induced him to hold out against the repeated advice of his true friends to take pension. Poor fellow, he paid the penalty of this mistake with his life. He was most kindly nursed on his death-bed at Dera Ismail Khan by various officers, to whom he was a perfect stranger, as well as by those of us connected with his work who were summoned by telegraph.”

Mr. Wiseman was elected an Associate of the Institution on the 6th of February, 1877, and was transferred to the class of Associate Member in 1879 and to that of Member on the 14th of February, 1888.

WILLIAM BRERETON BESTIC was born on the 5th of January, 1859. After being educated at the Royal Indian Engineering College, Coopers Hill, he was appointed an Assistant Engineer in the Public Works Department of the Government of India in September 1879. In accordance with the usual custom, he then underwent a year's practical training in England, after which he was posted at the end of 1880 to the Dacca Division of the Bengal Presidency. There he remained until July 1883, when he was transferred to the Darjeeling Division.

In the following October Mr. Bestic was appointed Under-Secretary to the Public Works Department of Bengal. In February 1888 he added to these duties those of Under-Secretary to the Marine Department, and was promoted to Executive Engineer 4th-Grade in July, 1890, and to 3rd-Grade in September, 1891. In the spring of the latter year the Government of India formally acknowledged the valuable services he had rendered as a member of the Native Passengers Ships Commission.

He continued to hold this appointment for nearly ten years, till March 1892, when he was selected by the Government of India to assist in the drafting of the Merchant Shipping Bill, which was introduced in the Imperial Council only a few days before his death, accompanied by a eulogium from Sir Alexander Miller (Legislative Member of Council), that was a fitting acknowledgment of the services he had rendered.

On the conclusion of his work at Simla he was, in October, 1892, deputed to the special, and, what was thought, enviable duty of preparing a waterworks project for Srinagar, Kashmir, but had been there only a few days when he was seized with malignant smallpox, caught in the native town, and it terminated fatally after only five days' illness.

Thus was cut prematurely short what promised to be a very brilliant career. In the opinion of the Chief Secretary and the other chiefs of the P.W.D., he would have risen to the very highest posts open to good Civil Engineers. Mr. Bestic was elected an Associate Member of the Institution on the 6th of May, 1884.

HERBERT GEORGE HUXLEY, son of Mr. William Thomas Huxley, was born in London on the 10th of March, 1847. In 1865 he was articled for five years to Messrs. Richard Moreland and Son of Old Street, St. Luke's, where he gained a practical knowledge of mechanical engineering both in the workshops and in the drawing-office. On the expiration of his pupilage he went to Ireland for two years to take charge of the construction of the Navan and Kingscourt Railway for the contractor, Mr. John Edwards, of Dublin.

After the completion of that line Mr. Huxley was engaged from 1873 to 1877 for Messrs. Telford Macneill & Co. in superintending—in conjunction with the late Mr. W. J. Maxwell¹—the construction of the Beyrout Waterworks in Syria. In spite of many difficulties the works were successfully carried out, chiefly by native workmen, the supply being obtained from the Nahr-el-Kelb, or Dog River, to the source of which caverns, extending for miles underground, conveyed melted snow from the mountains of Lebanon.

On returning from Syria in 1877 Mr. Huxley undertook the management of the Steam Cooperage and Vat Company's works

¹ Minutes of Proceedings Inst. C.E., vol. lxvi. p. 384.

at Whitechapel, which post involved the maintenance in working order of a large amount of machinery. From 1880 to 1883 he was engaged for Mr. Edward Easton in preparing schemes for the water-supply of Barcelona, Vienna and Rosario. In 1884 Mr. Huxley proceeded to Weesp, in the Netherlands, to take charge for Messrs. Joseph Quick and Son of the construction of the "Vecht" water-supply for Amsterdam. On the completion of those works in 1888 he went to Moscow to prepare a scheme for the water-supply of that city. While there he contracted a severe chill, which on his return to England developed into influenza and pneumonia.

For the next four years Mr. Huxley was engaged upon various water projects for, amongst other places, Palermo, Vigo and Athens; he also designed constructional ironwork for buildings and reported upon mining and railway schemes. His health, however, had become permanently affected and he succumbed, after only three days' illness, to an acute attack of pneumonia on the 1st of June, 1893.

Mr. Huxley was a competent engineer in the branch of the profession to which he devoted himself; industrious and painstaking, his work was always good and reliable. He was elected an Associate of the Institution on the 1st of February, 1876, and was placed in the class of Associate Member on its creation in 1878.

HERBERT CHARLES ERSKINE VERNON, youngest son of Lieutenant-Colonel George Vernon, late Coldstream Guards, of Harefield Park, Uxbridge, was born on the 28th of September, 1851. After being educated at Harrow, he entered the Royal Indian Engineering College at Coopers Hill, from which he passed with honours into the service of the Public Works Department of the Government of India. The usual custom for young engineers thus appointed being to gain some practical experience before leaving this country, he spent ten months on the Chatham Dockyard Extension, under the late Mr. E. A. Bernays,¹ then Superintending Civil Engineer of all the Admiralty works at Chatham and at Sheerness.

Mr. Vernon landed in India in December, 1874, and in the following month was placed in charge of the Lucknow District Provincial Works, which post he held until March, 1876, when he

¹ Minutes of Proceedings Inst. C.E., vol. xci. p. 408.

was compelled by ill-health to return to England. On resuming work in the following December, after nine months' furlough, he was posted to the Kheri district in the North-West Provinces, of which he held charge until October, 1880, when he was transferred to the Saharanpur district. He subsequently served on the Meerut Provincial Division, of which he was in temporary charge from August to October, 1882, and on the Allahabad and Rohilkund Provincial Divisions, being promoted to Executive Engineer 4th-Grade, in May, 1883. In March of the following year his health, which had again broken down, compelled him to take fifteen months' furlough, afterwards extended to twenty-one months. On returning to India, Mr. Vernon was posted to the Agra and subsequently to the Meerut Division, having charge of the latter for nine months in 1886. On the 11th of May, 1886, he was promoted to Executive Engineer 3rd-Grade and in the following December was transferred to the Lucknow Division.

The climate of India was, however, too trying in Mr. Vernon's case and in March, 1887, he was once more obliged to take sick leave, this time for two years. Finding, however, that he could no longer hope to perform his duties in India and at the same time retain his health, he retired from the Public Works Department in 1890. Somewhat restored by rest and change, he returned to India in November, 1892, on a visit to his brother-in-law, Mr. J. Gibson, D.C., of Bahraich, in the province of Oudh. Relying too much on his partial restoration to health and being an ardent sportsman, he exposed himself too freely; the result was an attack of fever, to which he succumbed on the 15th of February, 1893.

As a Government official Mr. Vernon deservedly obtained the approval of his chiefs for hard and efficient work, in spite of ill-health, and for tact and sound judgment. He was specially commended for important services in connection with the visit of the Prince of Wales to India. Of a kind and straightforward disposition and of a liberal and generous mind, he made and kept many friends wherever he happened to be stationed. Mr. Vernon was elected an Associate Member of the Institution on the 4th of February, 1879.

SIR JAMES JOSEPH ALLPORT, born in 1811, was a son of the late Mr. William Allport, of Birmingham, who, as a manufacturer of small arms, executed large contracts for the English and other governments during the Napoleonic campaigns and also assisted

in establishing the Birmingham Proof House Company, of which at the time of his death he was Prime Warden. At an early age the subject of this notice was sent to Belgium to be educated. He returned to this country shortly before the death of his father, whose affairs involved him in considerable difficulties owing to the serious financial and commercial depression which had prevailed between the years 1820 and 1825.

Mr. Allport was 28 years of age when in 1839 he commenced his railway career in the service of the Birmingham and Derby Company as agent and representative for all descriptions of traffic at Hampton, the point of junction with the London and Birmingham Railway. He soon became manager and it was under his auspices that the fierce competition began between his line and the Midland Counties and the North Midland Railways, which ended in the amalgamation of the three companies in April, 1844, under the style of the Midland Railway. Mr. Frederick S. Williams in his work on "The Midland Railway: its Rise and Progress,"¹ states that, so great was the conflict between the Midland Counties and the Birmingham and Derby that the latter Company, in its endeavour to attract the London and Derby traffic, reduced its through fares to 2s. first-class and 1s. 6d. second-class over the 38 miles from Derby to Hampton, while the local fares between those two places were maintained at 8s. first-class and 6s. second-class.

At the amalgamation there was of course no room for three staffs of officers. The North Midland Company's manager became the manager of the new Midland, and as the Birmingham and Derby was the least important of the three, Mr. Allport's services were dispensed with. He had, however, already made his mark, and the Chairman of the Midland Company—Mr. Hudson, or "King" Hudson as he was popularly called—at once asked him to take charge of the Newcastle and Darlington Railway. Great efforts were being made at that time to establish an east coast route to Scotland and an important item of Mr. Allport's new duties was to organize a through service of coaches to bridge the gap between the Scotch and English lines. At that time the battle of the gauges was raging and, in order to show that the narrow gauge was not incompatible with high speed, Mr. Allport made a run from Sunderland to London and back with the account of Mr. Hudson's election as Member of Parliament for the former town. Leaving Sunderland at 5 p.m. he travelled *via* York, Normanton, Derby, Rugby and Wolverton to Euston, drove to *The Times*

¹ Library Inst. C.E.

office, where his manuscript was immediately set up in type and inserted with a leading article; and, armed with several impressions, arrived at Sunderland at 10 o'clock the next morning, before the announcement of the poll. The distance travelled was 600 miles, which, allowing for the two hours spent in London, gave an average of 40 miles an hour. During the six years of his connection with the Newcastle and Darlington line it developed into the York, Newcastle, and Berwick Railway. He was next, for three years, Manager of the Manchester, Sheffield, and Lincolnshire Railway, after which he returned in 1853 to take charge of the Midland.

Under the management of Mr. Allport the Midland rapidly developed from a series of local lines into one of the great trunk railways of the kingdom. The southern terminus of the line was then at Rugby, and for some years efforts had been made to get nearer to London. So great, however, was the opposition of its powerful competitors, the London and North-Western and the Great Northern, that the idea of amalgamation, first with the former and then with the latter, was for a time entertained. The Midland Company, with its 500 miles of railway and £17,000,000 of capital, could no longer be kept more than 80 miles from the metropolis, at Rugby, where it was delivering to the North-Western a large and constantly increasing goods and passenger traffic. At length, in 1853 an Act was obtained for an extension from Leicester to Bedford and then on to Hitchin, whence running powers were granted over the Great Northern system to London. It was a time of financial depression and some difficulty was experienced in raising the necessary capital. It was not, therefore, until May, 1858, that the Leicester and Hitchin line was opened.

In the previous year Mr. Allport had retired from the service of the Midland in order to accept the post of Managing Director to Palmer's Shipbuilding Company at Jarrow-on-Tyne. He did not, however, entirely sever his connection with the Midland, for he was appointed to a seat on the Board of Directors of that Company. His new occupation was not destined to last long. In 1859 and 1860 most determined efforts were made by the London and North-Western, the Great Northern and the Manchester, Sheffield and Lincolnshire to effectually bar the Midland from access to Manchester and to the North. In the latter year, therefore, Mr. Allport was requested to resume the position of General Manager of the Midland, and it was mainly owing to his evidence before the Parliamentary Committees that the schemes of the rival companies were defeated. The latter,

however, still succeeded by mutual arrangements in shutting out the traffic of the Midland from Lancashire; the North-Western barred the way at Stockport, and the Manchester, Sheffield and Lincolnshire at Hyde. It became evident that a new policy must be adopted and strenuously carried out; the Midland must make itself, as far as possible, independent of its rivals. In spite of the great opposition of the North-Western and Great Northern, an Act was obtained in 1862 for an extension to Manchester through the Derbyshire dales. The works were at once put in hand and the line was opened on the 1st of June of the following year.

Another and even more important extension was now demanding Mr. Allport's consideration. Both the goods and passenger traffic to London were increasing so enormously that the accommodation and facilities provided by the Great Northern between Hitchin and King's Cross were totally inadequate. In 1862, when an Exhibition was held at South Kensington, nearly 1,000 Midland passenger trains and 2,400 goods trains were delayed between those two points. Moreover, the North-Western, which in the same year had carried from Rugby to London Midland goods traffic to the extent of nearly £200,000, was becoming less and less able to accommodate it. It was absolutely necessary that the Midland should have a line of its own to London and in 1863 an Act was obtained for the extension from Bedford to St. Pancras. The works, constructed to accommodate four lines of rails, were pushed forward as rapidly as possible; but it was not until the end of 1868 that the first passenger train ran into the magnificent station at St. Pancras,¹ with its roof of one span of 240 feet, its lower floor for the storage of Burton ale, its great hotel and its extensive goods depôt.

In the previous year, however, the Directors had created a temporary panic amongst the shareholders by applying to Parliament for power to raise additional capital to the extent of £5,000,000. This was rendered necessary, not only by the excess of the actual cost of the extension to London over the Parliamentary estimates, but by three other new works then in progress—a direct line from Chesterfield to Sheffield, which had hitherto been approached by a branch from Masborough; direct communication with Liverpool, in conjunction with the Great Northern and the Manchester, Sheffield and Lincolnshire; and an extension from Settle to Carlisle, which, with the co-operation of

¹ Minutes of Proceedings Inst. C.E., vol. xxv. p. 284, and vol. xxx. p. 78.

the Glasgow and South-Western, would enable the Midland to share, for the first time, in the enormous traffic carried on between this country and Scotland. The necessary powers for these three schemes had been obtained in 1864, 1865 and 1866 respectively. Mr. Allport, however, reassured the shareholders, and the additional capital was raised without difficulty. One sacrifice was made to economy—the great hotel at St. Pancras was built without the storey intended in Sir Gilbert Scott's original design to accommodate the officials of the Company who still remain at Derby.

In the year 1872 occurred one of those events in the history of the Midland Railway Company with which Mr. Allport's name will always be associated. It was decided to run third-class carriages by all trains, an innovation which, although it met with great disfavour from his competitors, he declared to be for the benefit of the public and of the railway companies alike.¹ The result was a remarkable improvement in the receipts and in the number of passengers carried, and it was found that, as duplicate trains were no longer needed, the expenditure was actually diminished, instead of increased, as the opponents of the change had predicted. Another result, however, soon became apparent—that the second-class traffic was largely diminished, while the third-class traffic enormously increased. In 1873 it was found that the revenue from first-class passengers was about 8*d.* per mile, that from second-class 7*d.*, while that from third-class was no less than 2*s.* 8*d.*, or more than twice as much as the two higher classes together. It was clear, therefore, that the trains must be carrying a large and increasing proportion of dead weight in the form of empty second-class carriages, and hence Mr. Allport was induced to consider whether it would not be better to abolish that class entirely. In order that the second-class passenger should not suffer, he reduced the first-class fare to the second-class scale. Judging from past experience he anticipated that this change would result in no loss of revenue but in economy of working, lightening of trains and greater punctuality. This revolution, as it was called by the daily press, startled the railway world and the public generally, and a storm of criticism and opposition ensued. Mr. Allport, however, stood firm and, as the arrangements for the working of the new policy came to be seen, it was found that the improvements in the third-class carriages were so great that the actual result of the change was to provide

¹ Minutes of Proceedings Inst. C.E., vol. xli. p. 62.

first and second-class accommodation at second and third-class fares. The introduction of Pullman carriages at this time was due to Mr. Allport's enterprise—an innovation which was at once successful and destined to be developed into a system of luxuriously-appointed sleeping- and dining-cars, privileges to which third-class passengers are now admitted.

Another reform which Mr. Allport effected about that time was the purchase of something like forty thousand wagons, principally coal wagons, previously owned by no less than three hundred different proprietors. He had stated in a discussion on "Railway Rolling-Stock" before this Institution, that it was the interest of all railway companies to possess the entire rolling-stock of their lines.¹ The number of accidents occurring with the wagons of private owners, over the construction of which the company had no proper control, was much larger than with the railway's own stock, and the cost and labour of marshalling and shunting empty wagons, when mixed together, in order to deliver them at the respective collieries to which they belonged, were extremely great.

In the year 1880 Mr. Allport, whose health was then in a precarious condition, felt obliged to resign the post which he had so long held. Thinking that by so doing they were treating him much more generously than by granting him a retiring pension, the shareholders of the Midland voted him a sum of £10,000. Relief from toil and responsibility, however, seemed to inspire him with new life, and he showed, not only in connection with the Midland, of which he was elected a Director, but also on the Boards of smaller undertakings, that he had still a dozen years of work left in him. In 1884 the somewhat tardy honour of knighthood was conferred upon him, and two years later he was appointed a member of the Royal Commission on Irish Public Works.²

Sir James Allport died at the Midland Grand Hotel, St. Pancras, on the 25th of April, 1892, from acute inflammation of the lungs, the result of a chill. No tribute to his work for the great company with which he was so closely identified can be more fitting than that given by Mr. Williams in the "History of the Midland Railway," from which the following passage is quoted:—

"In the remarkable development of the Midland system that has taken place during the last few years, Mr. Allport has had his full share of responsibility and toil. His devotion to the interests of the company has been, in the opinion at

¹ Minutes of Proceedings Inst. C.E., vol. xlv. p. 134.

² Report in Library Inst. C.E.

least of rivals, only too absorbing; and vehement are the attacks that have, in consequence, sometimes been made upon him. Yet the heat of controversy has generally been tempered with some admission of the remarkable ability with which the policy of the Midland has been defended. 'I admit, and I admit freely,' said Mr. Liddell, in a case in which he was opposing the Midland Company, 'and I must compliment Mr. Allport on his great accuracy and his singular power of answering complaints of this sort. I think it a most remarkable thing, the manner in which he can answer those complaints; and that he has done it in many cases I admit.'

"Such a life as that of Mr. Allport during the years that have witnessed the development of the Midland system must necessarily have been a life of conflict. To carry on negotiations which affected thousands of shareholders, tens of thousands of travellers, and millions of money; which have retarded or hastened the growth of towns, the progress of commerce, the social and political relations of the nation; to have been concerned in events by which the lines of the Company have increased to 1,200 miles in length, by which its capital has been augmented to more than £50,000,000, and by which the income has increased to £5,000,000 a year, could not have been done without a practical sagacity, a mastery of detail, and a persistency of will which ought not to pass by unnoticed. To sit hour after hour, and day after day, giving evidence before a Committee of Parliament, explaining the policy of a Company, and the justice or expediency of a Bill; to be ready with an infinite variety of details and dates, and names and negotiations respecting the history and administration of the Company; to meet the designedly ambiguous or misleading inquiries of opposing counsel; to parry their astutely delivered thrusts; to show how a new treaty may be negotiated without compromising the validity of an old one, and how a new line may be made into the territory of an old ally without a breach of equity—to do this before critical professional witnesses, while every word is recorded for future reference and use; and to do this till the questions and answers fill a hundred and fifty pages folio consecutively: all this demands qualities which it will be allowed are rare and remarkable."

Sir James Allport was a Justice of the Peace for the county and borough of Derby, and from 1853 to 1880 was a Lieutenant-Colonel in the Engineer and Railway Volunteer Staff Corps. He was elected an Associate of the Institution on the 7th of March, 1865, and frequently took part in discussions on railway matters. In addition to those already referred to, he spoke during the course of debates on communication between passengers and guards,¹ and on uniform gauge.²

HERBERT HOWARD-KEELING was born at Tottenham, Middlesex, on the 9th of October, 1829, and was educated first at a private school and subsequently at King's College, London. On leaving the latter in 1849 he was articled for five years to the late

¹ Minutes of Proceedings Inst. C.E., vol. xxvi. p. 94.

² *Ibid.*, vol. xxxv. p. 310.

Mr. James Samuel,¹ who at that time held the position of Resident Engineer on the Eastern Counties Railway. Young Keeling assisted in the construction of part of that line and was afterwards placed in the Locomotive Works at Stratford. During the latter part of his pupilage he went, with Mr. Samuel's permission, to Russia, to test some suspension-bars for the Kieff bridge, for his uncle, the late Mr. Thomas Howard,² head of the firm of Howard, Ravenhill & Co., of the King and Queen Ironworks, Rotherhithe.

On the expiration of his articles in 1854, Mr. Keeling entered these works as an assistant and seven years later he became a partner in the firm. At the same time he assumed—on his marriage with his cousin, a niece of Mr. Thomas Howard—the surname of Howard-Keeling. The firm enjoyed a considerable reputation and turned out ironwork of the heaviest description for marine and other engines, as well as links with enlarged ends used in the construction of Warren girders. After the death of Mr. Howard in 1872 the works were closed and Mr. Howard-Keeling retired from business. From that time he lived quietly at Eltham in Kent, taking an active part in all the charitable and social institutions of that place and serving as a guardian of the poor for the parish of Lewisham. His death, which took place on the 7th of June, 1893, at Merlewood, Eltham, was caused by a riding accident—his horse, stumbling on a stone and falling upon him, broke his collar-bone and one leg. So severe were the injuries that he died in a few hours, although he suffered but little pain.

Mr. Howard-Keeling enjoyed the esteem and confidence of several eminent engineers by whom his firm was employed. He was a Member of the Institution of Mechanical Engineers, a Liveryman of the Ironmonger's Company, and not long before his death took up the freedom of the City. In private life he was, as already indicated, kind and generous, a pleasant companion and a staunch friend. Mr. Howard-Keeling was elected an Associate of the Institution on the 14th of January, 1862.

JOHN TOPHAM, eldest son of the late Rev. James Jerom Topham, was born at Dudley on the 2nd of April, 1833. It having been determined that he should adopt the profession of engineering, he was, on leaving school, placed as a pupil in the

¹ Minutes of Proceedings Inst. C.E., vol. xxxix. p. 280.

² *Ibid.*, vol. xxxvi. p. 294.

works of Messrs. Miller, Ravenhill and Company,¹ Marine Engineers, Glasshouse Fields, Ratcliff. On the expiration of his articles he was for a short time in the service of the Spanish and Portuguese Screw Navigation Company and subsequently in that of Messrs. Sharp, Stewart and Company for eighteen months.

In 1857 Mr. Topham started business on his own account as a Consulting Engineer. An extremely quiet and reserved man, he spoke but little of his own affairs. It has been impossible, therefore, to obtain information as to the works upon which he was consulted or with which he was otherwise connected. It is known, however, that for a time he acted as engineer to the Inter-Colonial Royal Mail Steam Navigation Company and that he subsequently became a partner in the firm of Bevington, Topham and Cortould of Spa Road, Bermondsey.

Mr. Topham died in London on the 6th of June, 1893, from an internal cancerous growth. In disposition he was, although proud and reserved, most affectionate and generous. His spare time was devoted principally to the study of literature. Mr. Topham was elected an Associate of the Institution on the 10th of January, 1860.

. The following deaths have also been made known since the 26th of July, 1893:—

Members.

ANDERSON, JOHN PHILIP COETLANDT; born 24 January, 1831; died 14 August, 1893. (<i>Heart disease.</i>)	February, 1845; died 30 August, 1893. (<i>Paralysis.</i>)
DEPREE, CHARLES LAMBERT; born 19	SUTTER, ARCHIBALD; born 26 Jan., 1829; died 30 Aug., 1893. (<i>Heart Disease.</i>)

Associate Members.

CROOK, CHARLES RICHARD ERNEST; born 17 September, 1863; died July, 1892. (<i>Heart Disease.</i>)	JOHNSTON, JOHN MONTGOMERY; born 8 March, 1857; died 1 September, 1893. (<i>Consumption.</i>)
EVELEGH, LEWIS FREDERICK; born 17 May, 1858; died 17 August, 1893. (<i>Heart disease, and tuberculous disease of the kidneys.</i>)	JONES, HODGSON MONTEITH LAYARD; born 31 October, 1813; died 27 August, 1893. (<i>Diabetes.</i>)

Information as to the professional career and personal characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 14 September, 1893.

¹ Minutes of Proceedings Inst. C.E., vol. xx. p. 152, and vol. lxxxix. p. 496.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS
AND PERIODICALS.

Cements.

By Professor CAMBESSÉDÈS, of the Douai School of Master-Miners.

(Bulletin de la Société de l'Industrie Minérale, 1892, p. 1181.)

The invention of quick-setting cement is ascribed to James Parker, who is said to have discovered it so recently as the year 1796. Portland cement was discovered by a bricklayer, named Joseph Aspdin, in 1824. The progress of the cement industry in France is described by the Author in a brief historical sketch; after which, he treats of the choice of materials for cement-making. The more regular the bed, the more uniform will the material of which it consists be in its property of hardening under water, and the greater its value. Deposits far removed from the Keuper beds and the Paris basin, for example, the Oxford clays of Frangey (Meurthe-et-Moselle), are the most suitable met with in France, because they contain less gypsum, a mineral sometimes so detrimental to the quality of cement. The Author shows how the value of a deposit which it is proposed to utilise may be determined by wet and dry methods.

The various kilns used for burning the cement-material are described, namely, the ordinary intermittent kiln; the English, or Johnson kiln; the Hoffmann continuous kiln, in which the compartments are used successively, the contents of each being allowed to cool *in situ*; and the recently invented Dietsch continuous kiln, in which the burning is effected on an upper, and the cooling on a lower floor. The Author deals then with the sorting of the burnt material, noting that well-burnt rock is very dense, black or greenish-black; less well-burnt rock is grey, or greenish-grey; the unburnt portion is clear yellow or yellowish-brown, and of low density, and is set aside to be re-burnt; while the powder due to ashes from the fuel, mixed with the cement, is grey and heavy, and it is mixed in small proportions with the well-burnt rock. Yellow powder is rejected; and a yellow Portland cement would accordingly be regarded unfavourably. Fine grinding of the burnt product from the kiln is sometimes, notably in the case of phosphate of lime with felspar, a costly operation by reason of the great hardness of the rock; but such pulverising is essential, the material being sifted through revolving or shaking sieves.

The remainder of the paper consists, principally, of a *résumé* of the experiments and opinions of the leading French authorities on cement, namely, Le Chatelier, Candlot, Bonnami, Alexandre, Frémy, and others. According to Candlot, the composition of Portland cements varies within the following limits:—

Silica	20·30 to 26·10
Alumina	5·20 „ 10·60
Oxide of iron	2·10 „ 5·30
Lime	58·12 „ 67·31
Magnesia	0·33 „ 2·30
Sulphuric acid	0·26 „ 1·78

The specific gravity varies from 3·050 to 3·175.

The Author treats of the chemical reactions in the kiln; the setting qualities and powers of resistance of cements in various circumstances; cement-testing; adulteration; causes of deterioration, including the presence of free unslaked lime (which slowly swells at the moment of setting), sulphate of lime (which is especially injurious in cement used in marine work), and magnesia; and the trial of hydraulic materials. Under the last head, the Author remarks that, the only useful information which a chemical analysis of a cement can afford, is whether it contains an excess of base or not; and that mechanical tests, exaggerating by all possible means the actual causes of deterioration and destruction, are also necessary.

In conclusion, the Author observes that he has had occasion to examine numerous samples of cement, and has found that the blue mortars are possessed, as a rule, of great power of resistance; and, with Le Chatelier, he is of opinion that, for mining engineers and practical men who have not, like the State departments, laboratories for the testing of cements, the colour of the mortar is, perhaps, one of the best and most practical indications of its general properties. Thus, if the mortar be too yellowish, or too whitish, it will be regarded with disfavour.

A. H. C.

*Portland Cement and its Uses in Building.*¹

(Der Portland Cement und seine Anwendung im Bauwesen. Berlin, 1892.)

This book of 310 pages contains much useful information with regard to the different uses of Portland cement, together with some observations on the different methods of testing adopted in Germany. The properties of this material are dealt with in detail, together with the usual adulterants. The method of testing recommended is that prescribed by the German standard rules according to which both crushing and tensile tests are made. The

¹ The original is in the Library Inst. C.E.

crushing test after twenty-eight days is considered the final one, although the tensile strength is also used as a means of checking the deliveries of cement. Some of the more important testing-machines are described and illustrated. The different methods of making cement mortar for building purposes are explained in detail, and a number of directions are given for plastering with cement and lime-cement mortar.

More than half the work deals with the various uses of concrete, and the physical properties of that material are fully explained. The different varieties of concrete are detailed and the advantages of each discussed. A number of machines and appliances for mixing and depositing concrete are illustrated and described. Numerous illustrations are given of the use of concrete for foundations, locks, weirs, docks, breakwaters, and reservoirs, many of the drawings being taken from these volumes. The use of concrete for the construction of houses is considered, and examples of works executed are given and illustrated. The treatment of cement generally, when used in situations exposed to the air, is also dealt with. Much space is devoted to Monier's system of concrete construction; in which a web or framework of wrought-iron is used in conjunction with Portland cement concrete.

W. F. R.

Experiments on the Action of Magnesia in Portland Cement.¹

By Dr. L. ERDMENGER.

(Excerpt Thon-Industrie Zeitung, 1893.)

The raw material for these experiments was a dolomitic limestone, which was sifted through a sieve of one thousand six hundred meshes per square centimetre (ten thousand three hundred and twenty-two meshes per square inch) before use. Two series of experiments were made; in one the magnesia replaced part of the lime present in Portland cement, in the other the usual quantity of lime was retained and magnesia added in various proportions. From previous investigations the Author is of opinion that magnesia cannot be considered as an equivalent for lime in Portland cement, and cannot therefore replace any part of that substance which is present in a normal cement.

A number of cements were made in which the proportion of magnesia varied from 0.8 to 23.3 per cent. On the whole the specific gravity increased with the proportion of magnesia, although the increase was scarcely perceptible when the percentage of magnesia was very small.

A number of rods 100 millimetres (3.937 inches) in length and 5 square centimetres (0.775 square inch) in section were made of

¹ The original is in the Library Inst. C.E.

the different samples of cement. Immersed in water, the whole of the test-pieces expanded, especially those made with neat cement; with 3 parts of sand the expansion was not so great. The observations were continued for a period of ninety weeks, when those cements with the highest proportions of magnesia showed signs of disintegration.

Exposed to the air, all samples contracted, and none of them showed decomposition of a serious nature. With the increase in the proportion of magnesia, beyond a certain point there was a diminution in the amount of contraction, and the Author considers that this might ultimately result in expansion, and in the destruction of the cement after a number of years. It is also considered that the changes would have been more considerable had the test-pieces been exposed to the atmosphere instead of being kept under cover.

The Author is of opinion that when cements containing much magnesia are mixed with a large proportion of sand the effect of this impurity may be so toned down that disintegration of the masonry or concrete need not necessarily ensue.

In order to ascertain rapidly whether the magnesia in a cement is present in sufficient quantity to prove injurious, the Author recommends his high-pressure steam-test. In carrying this out the briquettes are allowed to harden for three days at the ordinary temperature, and are then exposed for about six hours to steam at pressures varying from three to twenty atmospheres. The Author considers that this test, which has now been in use for fifteen years, gives, when properly carried out, the means of forming a complete and rapid judgment on a cement containing magnesia. On the other hand, it has been stated that even the best cements fail to stand this test.

W. F. R.

Concrete-and-Iron Bridge over the Neutra, at Neuhäusel.

By JOSEF SCHUSTLER.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins, 1893, p. 305.)

This bridge, recently constructed at Neuhäusel in Hungary, is especially interesting in the system of construction adopted, all parts being of concrete, the material in the arches being bedded round iron framing. The structure consists of six spans each of 55 feet 9 inches, with two abutments and five piers, the clear waterway therefore being 334 feet 6 inches. The rise of the arches is 3 feet 8½ inches, or $\frac{1}{12}$ span; thickness of crown, 10 inches, thickness at haunches, 4 feet 6 inches; total width of arch (over parapets) 19 feet 8 inches. In this width are laid thirteen skeleton girders or frames, at about 1 foot 7½ inches apart, and consisting of a horizontal upper member, continuous from one abutment to the other, and a segmental or parabolic lower member.

The framing is anchored down through each abutment, but only bolted on each pier for facilitating the construction. Both members consist of two angle-bars riveted together. There are no diagonals or verticals, the concrete being filled in to form a solid spandril, the iron framing thus dividing the thrust and the tensile strain with the concrete mass. The maximum strain at the crown is 410 lbs. per square inch, which, with Portland cement concrete at 1 : 6, allowing twenty-eight days setting, is within one-fifth of the ultimate breaking-strain. The maximum tension on the upper member of the iron framing, under the most unfavourable conditions of load, is 2·59 tons per square inch, and on the anchor-bolts 4·07 tons per square inch.

The Author describes in detail the process of construction, and the modifications necessitated by the unanticipated passing through a considerable depth of soft subsoil. In forming the arches, the width between each two girders was filled in, over one entire span, in one day, and well rammed perpendicularly and tangentially, so as to secure its uniform consolidation. The entire work occupied four months, and, allowing five weeks for the extra foundations, the structure, as originally planned, was completed in about twelve weeks. The cost was a little over £3,000. On the removal of the centering, the subsidence in the several arches was as follows :—

Arch.	Centering removed after	Subsidence.
No.	Days.	Inch.
1	43	0·079
2	41	0·236
3	40	0·473
4	36	0·551
5	32	0·670
6	31	0·591

Noting the marked difference in the arches in which the centering had been allowed to remain for the longest time, the Author is of opinion that in the case of such flat arches it would be advisable to allow the centering to stand for six weeks before striking. There was no subsidence in either piers or abutments. The structure was tested in January last, first with a dead load composed of an additional layer of metalling, $10\frac{1}{2}$ inches thick, uniformly spread, and corresponding to 82 lbs. per square foot, and then under an exceptionally heavy live load. The maximum temporary deflection was 0·138 inch, or $\frac{1}{5,000}$ of span; maximum permanent set 0·031 inch, or $\frac{1}{20,000}$ of span.

P. W. B.

Wind-stresses in Continuous-girder Bridges Resting on Elastic Piers. By F. CHAUDY.

(Mémoires et compte rendu de la Société des Ingénieurs Civils, May, 1893, p. 621.)

To ascertain the distribution of stress, it is first necessary to discover the reactions between the bridge and the various piers. This can be done by writing down from well-known formulas a series of simultaneous equations in which the unknown quantities are the various reactions. Each of these equations expresses the fact that the deflection of the girder at the head of one of the piers under the action of the wind in one direction, and the reactions of all the piers in the other, is equal to the deflection of that pier itself. There are as many equations as unknown quantities.

These equations can only be formed on the assumption of a constant moment of inertia and form for the girders and piers. With a varying section, graphic methods of an analogous character can be used to solve the problem.

C. F. F.

On the Construction of Walls with Skew Surfaces.

By J. CONARD.

(Annales des Travaux publics de Belgique, 1893, p. 359.)

This Paper is a description of the methods used in designing and building walls by which the abutments of a bridge with vertical faces were joined on to the neighbouring retaining walls of the river banks, the faces of which in section were parabolic.

The first step was to lay down horizontal curves for the coping and foot of the junction wall. These were made reverse curves, designed to facilitate the flow of water along the wall as much as possible. The form of the wall was then defined by a series of parabolas in vertical planes normal to the curve of the foot. Each of these parabolas has a vertical tangent where it intersects the curve of the coping, and this point is the vertex of the parabola. The further condition that it must pass through a given point on the lower curve defines the parabola completely.

The foot of the wall was made with a course of stone, and the rest of the wall of brick set entirely as headers. The stone was cut in steps on the top bed, each step being of one brick thickness, so as to take up the difference in length of the successive parabolas along the face. The upper part of the wall visible above water thus shows a series of almost perfectly horizontal courses.

The article is illustrated by diagrams.

C. F. F.

Construction of Watertight Masonry by Compressed Air in Small Caissons. By J. KRAUS.

(Le Génie Civil, vol. xxiii., 1893, p. 89.)

This communication is in the form of a letter with two illustrations, and describes the method adopted for constructing a dry dock in the harbour of Talcahuano (Chili), by French contractors. The site of the dock is below water-line in a fairly well sheltered bay, and there is a foundation of impermeable rock.

Two caissons are used, measuring 69 feet by 21 feet by $6\frac{1}{2}$ feet, and with these the greater part of the dock walls is being built. When the walls are finished the dock will be dried in order to put in the floor and also the interior facing of the walls. The base of the walls being greater than the width of the caisson, the caissons have to be moved both transversely and longitudinally to cover the whole ground. The work is raised in layers of $19\frac{1}{4}$ inches, and is all done in the dry, except the channels between adjoining blocks occupied by the edges of the caisson. Thus, when the caisson has been raised $19\frac{1}{4}$ inches, and moved horizontally as well, so that its edges rest on finished work, a channel is left where its edge stood in the last position occupied. This channel will have 18 inches or so of water in it, and is filled by putting masonry at its ends under water and then emptying the channel by buckets. One of the pumping-wells has been built in the same way. The Author claims that on this system a large mass of perfectly continuous masonry can be constructed without the expense attaching to large caissons.

C. F. F.

Railway from Lauterbrünnen to Mürren (Switzerland).

By — MOUTIER.

(Revue générale des Chemins de fer, vol. xvi., 1893, p. 22.)

The mountain railway described by the Author is divided into two sections, the first, extending from Lauterbrünnen to Grütsch, a distance, horizontally measured, of 1,320 yards, being worked by cable, and the second portion, 2 miles 1,230 yards in length, by electric locomotives.

The inclines of the cable line vary from $42\frac{1}{2}$ to 60 per 100.

The permanent way is formed by two parallel concrete courses 1 foot 7 inches square, to which are bolted wooden lateral beams $7\frac{1}{4}$ inches $\times$ $8\frac{1}{4}$ inches in section, and carrying iron sleepers 7 feet 8 inches in length. The rails are three in number, laid 3 feet 3 inches apart, the central one being common to the up and down tracks. There are two carriages only, connected by a cable passing round a drum at the upper end of the line. The carriages

pass at a point midway between the terminals, the line being opened out here to form two separate tracks. The cable weighs 7 lbs. per yard, and is composed of 126 steel wires, its breaking-strain being calculated at $62\frac{1}{2}$ tons.

The motive power is obtained by charging the upper car with water, each car being fitted for this purpose with a tank of 247 cubic feet capacity. A charge of 7 tons of water is required, with an empty descending car, to raise the lower one with its maximum load of forty passengers. Telephonic communication between the two stations enables the requisite amount of water to be taken into the car. During the journey down the water is regularly discharged into a channel prepared for its conduction. The weight of an empty carriage is 7 tons 16 cwt., or with the water reservoir full 14 tons 16 cwt., which on an incline of 60 per 100 corresponds to a strain on the cable equal to $7\frac{1}{2}$ tons. The safety-coefficient is therefore one-eighth. The difference in altitude between the two terminal stations amounts to 2,210 feet.

The second section of the line, worked by means of electric locomotives, does not include a gradient of more than 1 in 20. The rolling-stock consists of three locomotives, two passenger- and two goods-wagons. The locomotives, weighing 7 tons 4 cwt., each contain two motors, the movement of which is transmitted to the axles by means of gearing reducing the speed in the proportion of 5 to 1. The current supply is by an overhead conductor from which it is collected by a brush on the locomotive. The speed is about 7 miles per hour and the power developed 30 HP. by 36 amperes at 600 volts.

The energy is obtained from turbines, the maximum output of which is 150 HP., though 120 HP. is found sufficient for normal service. The generator is keyed directly on to the turbine-shaft, and has an output of 150 amperes at 600 volts with 750 revolutions. The overhead conductor is fed at three points, and the rails, which form part of the return circuit, are connected at the nearest point to the generator. Each rail is connected to the next by a soldered copper strip, and the two rails are connected at intervals of 110 yards. The total expenses of construction and equipment have amounted to £60,000.

Sketches are given of details of construction, together with plans and sections of the route.

F. E. B.

The Argentine Railways. By G. KEMMANN.

(Excerpt Archiv für Eisenbahnwesen, 1892.)

This is a pamphlet, in two parts, accompanied by a map to a scale of about 85 miles to an inch, showing the whole of the railway systems of Chili and Argentina.

A general description of the geographical features of the country

is given, and of the areas cultivated and not cultivated, and the acreage of the various crops. The amount of exports in 1886 was £13,966,968 (\$69,834,841), and the imports £19,081,749 (\$95,408,745). The navigation of the principal rivers is also described.

The main lines of railway radiate from the most important river or sea-ports on the east; the principal being Buenos Ayres, Rosario and Santa Fé, and the connection of the railways of Argentina with those of Chili has been the subject of consideration for a number of years past. Numerous routes have been studied more or less carefully, but the great difficulty has been to trace a line the grades of which should be workable in crossing the Andean Chain, which throughout its length in the territory under consideration rises abruptly from the comparatively level Pampas. On the map accompanying the Paper is shown the course of the Trans-Andine railway, the only one out of the many lines projected which is actually in course of construction. This crosses the Andes by the Passes of Uspallata and De la Cumbre, situated in about the same latitude as Valparaiso. The various other projects for crossing the chain at other passes are reviewed.

The gauges adopted both in Chili and Argentina are a broad gauge of 5 feet 6 inches, the normal gauge of 4 feet 8½ inches, and others of 3 feet 3½ inches, and 2 feet 6 inches, the latter in Chili only. The gauge adopted for the above mentioned Trans-Andine line, crossing the Andes between Mendoza and Valparaiso, is 3 feet 3½ inches.

The construction of railways in Argentina is, as a rule, very simple, running as they do over grassy plains flat as a table.

In the Andes, however, the difficulties are very great, protection against heavy snow-falls having to be provided, and bridges constructed across water-courses which in summer are waterless and in winter converted into roaring torrents.

A full description is given of the administration of the various government departments, including that of railways, the granting of concessions, &c.; also a review of all the lines that have been constructed up to the year 1890, and a series of tables giving their lengths, gauge, capital, number of employees, traffic returns and receipts, and a list of the most important works.

D. G.

Screw-Bolts for Fixing Rails on Wooden Sleepers.

By JULES MICHEL.

(Revue générale des Chemins de fer, vol. xvi., 1893, p. 337.)

The Author gives the results of trials made on various French railways since 1863, leading to the adoption of screws in the place of spikes, and describes the alterations made in the shape of the former.

The Paris, Lyons and Mediterranean Company, after using an iron screw, decided in 1881 to obtain greater strength by the use of steel, instead of by increased size. With this metal the thread could be formed by hot rolling, and a perfectly even result be produced.

In 1889 further tests were made with the object of increasing the pitch of the thread and so facilitating the insertion.

The use of steel, together with a slight reduction in the diameter of the hole bored in the sleeper, increased by 15 per cent. the effort necessary to withdraw the screw to the extent of $\frac{1}{4}$ of an inch, raising it from $4\frac{1}{2}$ to $5\frac{1}{4}$ tons. The increase of the pitch of the thread from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch effected a further improvement of 10 per cent., whilst a further increase of the pitch to $\frac{5}{8}$ inch reduced the resistance. It was found by experiment that no advantage was gained by the thread, instead of being in the section of an isosceles triangle, having that of a rectangle. The Author considers that a further improvement in the total resistance to withdrawal might be attained by increasing the depth of the thread, to more nearly equalise the breaking-strain of the bolt *per se* and the resistance of the wood laying between the threads.

The screw, as now adopted by the Paris, Lyons and Mediterranean Company, has nine threads; the pitch is $\frac{1}{2}$ inch, total length 7 inches, length of screw $4\frac{3}{4}$ inches, diameter of same $\frac{3}{8}$ inch, projection of thread $\frac{1}{8}$ inch, resistance in new wood 5 tons 16 $\frac{1}{2}$ cwt. and 5 tons 5 cwt. in wood having been in service for nine years.

A plate is given showing the particulars of various screws previously or at present used by the Paris, Lyons and Mediterranean, and other French railways.

F. E. B.

Train-Heating: Trials made by the Eastern Railway of France.

By F. LANCRENON.

(Revue générale des Chemins de fer, vol. xvi., 1893, p. 264.)

These trials were made between 1891 and 1893, their object being the improvement of the system of heating, previously effected by means of foot-warmers.

The Author points out that of the many difficulties attending the use of steam, including stoppage by frost, loss of steam at the couplings, failure of discharge-cocks, and difficulty of regulation, some had been remedied in different countries, whilst others were inherent to the system. It was thought, however, that a solution of the problem would be attained by substituting for the slow current of steam a quicker current of steam and air, circulating in pipes open at one end; though such combination, when used

previously in Germany for the purpose of regulation, had not been successful.

It was at once recognized that the addition of air increased the rapidity of transmission of heat, and equalized the pressure in the main conductor, these effects being more noticeable with low initial pressures, large section of conductor, and frequent and important depressions in the level. A conductor, 865 feet long, and $1\frac{1}{2}$ inch in diameter, required ninety-seven minutes for its penetration by steam alone, or fifty-one minutes with frequent opening of condensed water discharge-cocks. With steam and air the time was reduced to twenty-six minutes, without intermediate discharge.

The difference in the action of steam alone, and a mixture of air and steam, is explained by the Author as due to a reduced condensation in the latter case, and the more efficient removal of condensed steam by the continuous current of air.

From a calorific point of view the results, as compared with steam-heating, may vary widely. If air is added to superheated steam the mixture has an intermediate temperature, never lower however than that of saturated steam at the pressure of the mixture; if added to saturated steam the temperature is not lowered beyond that corresponding to the pressure, a slight condensation supplying the heat to the air.

The method of distribution consists of a main conductor with three parallel and independent heating branch-tubes to the carriage. For the second- and third-class carriages the regulation is effected from the outside by the railway officials, and applies to all the compartments of one carriage; for the first-class carriages each compartment has its independent inlet from the main supply, controlled from within and without the carriage.

Both the steam and compressed air are supplied from the engine. After various trials the following apparatus has been adopted.

1. A general conductor, $1\frac{3}{4}$ inch in diameter, with stop-cock and coupling at each end of carriage, the coupling being $1\frac{1}{2}$ inch in diameter, thus increasing the speed of flow through that part of the circuit, and preventing the accumulation of water in the neck.

2. A direct-acting safety-valve regulated at 44 lbs.

3. A manometer on the main conductor.

4. A steam-inlet from the dome of boiler into the main conductor.

5. A special air-compressor with separate steam-supply, both similar to the Westinghouse apparatus. The pump discharges into the main conductor both its compressed-air and exhaust steam.

6. A valve allowing the brake-pump exhaust-steam to be discharged into the atmosphere or into the main conductor.

By means of the special pump the driver can discharge into the conductor an approximately equal volume of air and steam. The proportion of steam can be increased by the exhaust from the pump and, if necessary, by direct supply from the boiler.

For light trains of eight or ten carriages, it is thought by the Author that the brake air-pump might also suffice to supply the heating apparatus.

An automatic discharge-valve is used, and, after at first being fixed to the brake-van, is now made detachable, so that it can be coupled to the last vehicle whether brake-van or otherwise. It consists essentially of a circular metal expanding drum and capsule entirely filled with oleo-naphtha and terminating in a cone-shaped valve. When steam enters the chamber containing this apparatus the liquid expands, and the valve closes the discharge orifice; condensed steam then accumulates, the temperature is lowered, and the valve again opens.

The time necessary for the passage of the mixed gases has been found to vary: with twelve carriages, from 8 to 10 minutes; with fifteen carriages, from 12 to 16 minutes; with eighteen carriages, from 15 to 20 minutes; and with twenty-four carriages, from 28 to 35 minutes. To this must be added from 5 to 10 minutes for raising sufficiently the temperature of the heating-plates covering the pipes, the longer period corresponding to an atmospheric temperature of 10° to 15° Centigrade below zero.

With iron heating-plates their temperature has been found to reach: with one tube open, 40° to 50° Centigrade; with two tubes open, 50° to 60°; with three tubes open, 60° to 70°; whilst with brass heating-plates the temperature obtained with one tube equals that of the iron plates with two tubes, and two tubes with brass is equivalent to three with iron.

The cost and weight are as follows:—

	<i>£</i>	Cwts.
First-class carriage, three tubes	52	12
" without one tube under seat	48	10
Second-class carriage, five compartments	32	9
Third-class carriage, six compartments	36	10

Allowances to drivers of 4½ lbs. of coal per hour per carriage have been found ample.

Five plates of drawings are given showing the arrangements adopted and details of the apparatus.

F. E. B.

On the Regulation of Torrents. By CARLO VALENTINI.

(Giornale del Genio Civile, 1893, p. 201.)

The Author, in a long and comprehensive Paper (accompanied by a bibliographical appendix and illustrated by plates and by illustrations in the text) discusses the several phases and conditions of the action of mountain torrents, as well as of landslips and avalanches, and the protective and curative measures to be adopted.

In the simplest cases, and as an essential adjunct in all cases, plantation or afforestation is an efficient protective; for the development of vegetation is one of the primary obstacles to the surface accumulation of the destructive agents. The chief object, however, in dealing with the regulation of the bed of a torrent, so as to restrain it at all times within safe limits, is to produce and maintain an artificial slope of such inclination that solid matter will not overcome the frictional resistance, and will therefore not be carried downwards to develop destructive effects. Such slopes cannot be obtained without a gradual process of building up in successive stages. This inclination, at which permanence is secured, by absence alike of scour and of silting, is known as the "slope of compensation," or, expressed as to its ultimate results, the "slope of equilibrium"; and it is the most important factor of all, in dealing with the regulation-works on any torrent. Its precise value necessarily depends upon the volume of material carried in relation to the volume of water, as well as upon the length, sectional area of channel, mean velocity, and size and weight of material. Indicating the several factors as under, viz. :—

- a = size of one side of stone (assumed as a cube).
 v = mean velocity of torrent.
 p = specific gravity of stone: average (say) 2,400.
 ω = specific gravity of water: viz. 1,000.
 g = coefficient of acceleration.
 h = coefficient of material: for cubes = 1.5.
 f = coefficient of friction (stone on stone = 0.76; ditto on wet clay = 0.34).
 α = angle of bed of torrent with horizon.
 c = coefficient of density of suspended material.
 r = mean radius.

$$h \omega a^2 \frac{v^2}{2g} = 0.076 \omega a^2 v^2 (\text{i})$$
$$f(p - \omega) a^3 \cos \alpha (\text{ii})$$

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equation must be at least equivalent to the second, *i.e.*, the expression of minimum velocity is

$$0.076 \omega a^2 v^2 = f(p - \omega) a^3 \cos a,$$

whence

$$v = \sqrt{\frac{f(p - \omega) a \cos a}{0.076 \omega}} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For uniform velocity and small angles

$$v = c \sqrt{r \sin a} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and equating (1) and (2)

$$\tan a = \frac{f(p - \omega)}{0.076 \omega c^2} \cdot \frac{a}{r}.$$

This formula expresses the slope of compensation or equilibrium.

The originating causes of the presence of solid material in suspension are:—

- (1) Continual disintegration of surface by atmospheric action;
- (2) Destructive action of glaciers and avalanches;
- (3) Erosive action of the torrent itself; or
- (4) Soluble nature of the ground affected.

The form in which the deposit occurs varies with the origin and velocity; the velocity of the fluid diminishing with increased density, *i.e.*, with the greater amount of suspended material. In sudden flood-bursts, where the mass of material is borne in one onward rush, the deposit usually assumes a convex longitudinal section; while in a continued flow, the deposit settles with a concave surface. In transverse section the form is convex, the maximum deposit occurring along the centre. The slopes of the deposited masses vary from 70° and more in landslips to 40° in avalanches, while 10° is rarely exceeded in alluvial mounds and moraines are practically flat.

The first object to be attained in remedial works is to suppress the erosion and consequent slips; consequently the general form of procedure is to construct across the channel a succession of weirs or dams, so spaced that the line from the crest of one dam to the toe of the next corresponds to the slope of compensation. The space behind each dam is gradually filled up by deposited material and the new slope is permanently obtained on a raised bed. This process, with the planting of the side slopes, forms the first period in the works. It is next necessary to form small intermediate dams, which may be mere sills—either in masonry or in logs laid transversely and secured to others firmly driven in the ground. This is the second period of the works; and the third, or consolidation period—when all deposit of material has ceased—comprises the planting of small hurdle or fascine-work with shoots of willow or other trees. In general it is necessary to

begin by consolidating the upper portions of the channel and denuded ground, to reduce the risk of further injury to the lower lands; or if time presses, the channel may be divided into sections by dams of solid construction, and the several sections may then be dealt with separately and simultaneously, commencing from below.

In the case of torrents in steep ravines or deep valleys, where the slope of compensation is very rapid, the works comprise the construction of dams of dry masonry, or wood piling, or cribwork and rubble. In these cases it is essential that the work shall be well supported at the base, and it is therefore necessary to begin from below. In very deep ravines, especially where the channel is seamed with gulleys and ridges, the dams are not sufficient, but it is necessary to supplement them with hurdle-work and possibly with paving of the bed of the torrent. In flat reaches and over alluvial mounds it is requisite to obviate the deposit of fresh materials in different and uncertain directions, and an artificial channel has to be cut and systematized with cross-dams and groynes. It may be noted that on account of the great velocity to be resisted, it is useless to adopt groynes formed of timber casing and rubble-hearting. An economical and very useful measure is to use the blocks deposited in the bed of the torrent as rough or random pitching on the slopes, proceeding from the valley upwards. A system of dams and sills, hurdles and plantation, similar to that previously described, serves also to reinstate denuded surfaces and to protect them from further damage. The treatment varies according to the nature of the scour, which may be superficial or deep; *e.g.*, in the case of permeable strata overlying the smooth face of a bed of rock. It is sometimes advisable to divert the watercourse, either by a tunnel or by open cut in the rock, or by groynes or spurs; this is, of course, a radical cure. If the channel is characterized by much sinuosity, it is of importance to straighten it where practicable, so as to reduce as far as possible the effect of the current impinging on opposite banks. The drainage of the slope must also be taken into consideration, either by open trenches or deep drains; the former being generally—and especially in the transverse or intercepting drains—constructed in masonry, and the latter consisting either of tubes or of loose stone packing. The drainage must of course be regulated by the plane of saturation, which may be found (and in all large or important works should be found) by trial-holes, and this governs, approximately, the spacing of the trenches.

Denoting by p = the tangent of the angle of the plane of saturation with the horizon,

h = depth of plane from surface of ground,

H = depth of drain,

d = horizontal distance apart of drains,

$$H - h = p \frac{d}{2}.$$

Generally speaking the value of p is as follows :—

In sandy	soils from	0·015	to	0·02
„ loamy	soils „	0·025	„	0·03
„ ordinary	clay „	0·07	„	0·08
„ compact	clay .	0·09		

In the case of avalanches, the old practice was to erect banks or galleries or other defensive works close to the particular objects which they were intended to protect; but it is better to endeavour to cure the evil in its origin by preventing the initial scour and impeding the formation of great masses of the destructive matter, than to endeavour to arrest the downrush of the mass when it has acquired enormously accelerated velocity. The Author refers only to those situations where the value of property or the importance of highway communication justifies the necessary expenditure, as there must always be occurring numberless slips in the upper regions of the mountains with which, unless they threaten subsequent movement, it is quite unnecessary to deal. So far upwards as vegetation can exist, this is the best protection of all. Artificial structures are necessarily costly in these high regions; consequently in constructing masonry dams it is usual to build them in dry rubble, and to consolidate with mortar only the ends or springings and the crown. The most serviceable structure is a wall of substantial wedge-shaped vertical section and triangular on plan, with its apex pointing up the mountain-side, rising about 10 feet from the ground, and measuring about 25 feet in length on each face. Other protective works comprise stout palisading and broad masonry walls. In planning such works it is necessary to consider with which class of avalanche it will be chiefly requisite to deal; i.e., with (1) bottom or “warm” slips (where the lower layers of snow melt and slip away with the superincumbent mass); with (2) surface or “cold” slips (either loosened by violent wind or by the weight of a fresh fall of snow on previous layers); or with (3) glacial slips—the disintegration of glaciers.

When torrents originate in glaciers or have their course through surfaces much exposed to erosion, a more or less considerable amount of material will always be carried in suspension; and it is necessary as far as possible to confine the deposit to the mountain regions by constructing solid dams as near as possible to the outlet or mouth of the ravine. These are necessarily subject to continual addition and alteration, and can at any time be regarded as only in a state of transition. Such is the great dam at Pontalto, on the Fersina, commenced in 1537 and now attaining a height of 154 feet,¹ and the Madruzza and Cantanghel dams on the same torrent.

For a rapid fall of water with no great amount of suspended material it is useful to lay the bed with rough pitching and

¹ Minutes of Proceedings Inst. C.E., vol. cii. p. 351.

occasional transverse sills; thus a natural slope of about 40° may be practically reduced to one of little more than 10° . The fall may also be provided for by a succession of tumbling-bays or stepped dams, the apron being of sufficient length to take the curve of the fall in time of flood, and nearly horizontal in longitudinal section to counteract the velocity, and being covered by a sufficient head of water by means of a dwarf dam or sill, so as to absorb the impact of the falling water without injury to the paved surface.

A very effectual method of arresting the suspended material and clearing the water is to construct catchment basins; the channel widening out below any weir to a broad pool, with longitudinal dams at each side, and with two or more dams—either in piling or masonry—extending nearly across the whole width of waterway to intercept the material. Beyond these the pool narrows again to the normal channel, its outlet being through a network of piling. These obstacles collect practically all the suspended material; and the great point in working is, of course, to keep the basin frequently cleared out. The usual type of dam is vertical at back, with (i) front battered or (ii) the upper part vertical and lower part stepped. In plan it is either straight or curved. The usual dimensions are:—

(a) Masonry in lime-mortar, straight (type ii):—

For height = 15 feet (the minimum usually constructed)—

$$t \text{ (thickness at top)} = 0.42 h \\ \text{above 90 feet, } t = 0.62 h$$

Intermediate thickness, ranging between these limits for varying heights.

(b) Masonry in lime-mortar, curved:—

$$h = 15 \text{ feet, } t = 0.08 h \\ h = \text{above 90 feet, } t = 0.28 h$$

(c) Dry masonry, or with coping in mortar:— t to be increased by 20 per cent. for class (a), and 10 per cent. for class (b).

Thickness of coping or sill to resist force of water = a :—

h' = maximum head of water in flood.

l = width of sill.

Q = volume of maximum flood per second.

$$h' = \sqrt[3]{\left(\frac{Q}{1.77 l}\right)^2}$$

The minimum value of a is:—

$$0.44 h' \text{ for class (a) or (b)} \\ 0.58 h' \text{ for class (c).}$$

For general data, it may be taken that the volume of maximum flood (in the mountainous districts of Italy), for basins under 38 square miles in area, is equal to 1,720 gallons per square mile per second.

It is necessary to carry the foundations of the dams down to solid rock, wherever possible; and it is useful to form weepholes or drainage outlets to relieve the back pressure of water. The sills, in elevation, should be curved upwards at each side, to prevent scouring between the structure and the bank.

The stockades or hurdles with which the reclamation work is completed consist of rows of larch-stakes about 5 feet out of the ground and about 3 feet 3 inches apart; across these are interlaced branches of willow and stout withes, at spaces of 12 inches, these again cross woven with fresh willow twigs. All the willow is carefully cut with a view to its striking root and sprouting, so as to form a dense growth on the framework nucleus. These live hurdles are generally planted at an angle of 45° in the direction of the current, on each side of the channel, the intervening spaces being planted with ash, elm, or beech. Smaller (or "2nd class") live hurdles are from 1 foot 6 inches to 2 feet high. In one deep ravine in Canton Glarus, too steep for plantation, a series of these small hurdles was planted at intervals of from 3 feet to 10 feet; so that the space behind each was very quickly silted up. A fresh series was then planted on this raised surface; and the process being repeated two or three times, the valley was filled up to a gentle slope and then planted over, an artificial channel being formed to guard against erosion.

When stone is not available, dams are made of wood piling. In Switzerland this construction has been adopted up to heights of 33 feet and widths of 130 feet. Timber framework has also been employed with a filling of small rubble. The several types of construction of dams, sills, live hurdles, and other works are fully illustrated in the plates accompanying the Paper.

P. W. B.

Experiments on the Gauging of Running Streams.

By E. WALIN.

(Annales des Travaux publics de Belgique, 1893, p. 435.)

The Author considers that the only rigorous method of gauging is that of impounding the whole body of the stream in a reservoir of known dimensions, but that this method has not hitherto been used except for very small streams. The present Paper describes arrangements made for the purpose on the river Hoyoux, at Modave, where the flow is 40 to 50 cubic feet per second in the dry season. The river is diverted by a dam, over which it passes in floods, but by which at other times it is turned through a canal

to a weir forming the upper end of a steep channel. The water passing down this channel acquires considerable velocity; and, as the channel terminates at the foot of the slope with a vertical well, beyond which is the opening to the impounding reservoir, the water passes in a trajectory across the well when there is no obstruction. When, however, a gate is let down, closing the opening to the reservoir, the water strikes this gate and falls into the well, from which there is an outflow to the river below the dam.

The object of this arrangement is to ensure that the régime of the flow will be exactly the same, whether the water is flowing into the reservoir or past it. The gate is so made as to be capable of being opened and closed instantaneously. The basin holds 9,360 cubic feet of water. A few inches of water are usually left in the basin before commencing the experiment.

Three works of this kind have been established in the same neighbourhood for a total cost of £400. The Author thinks that where a suitable fall exists on a river the sum of £400 will cover the establishment of measuring apparatus on this system for a flow of 175 cubic feet per second.

Such an apparatus affords a useful means of investigation into the coefficients of flow over weirs and notches. Some determinations are given, made in this way, for the weirs in use with the apparatus above described, the edges of which are of $\frac{1}{8}$ -inch iron plate not bevelled.

The article is illustrated by a plan and sections of the works.

C. F. F.

The Water-Supply of Vienna. By V. BERDENICH.

(Gesundheits-Ingenieur, 1893, p. 346.)

Vienna, in the period between 1886–90, was supplied with water from four different sources, the bulk of the water being derived from the Kaiserbrunnen and Stixenstein deep wells. The volume thus obtained varied in quantity from 206,000,000 hectolitres in 1886 to a total of 273,000,000 hectolitres in 1888, falling again in 1890 to 251,000,000 hectolitres (5,524,000,000 gallons). This supply was supplemented by deep-well water from Pottschach to the maximum extent of 24,000,000 hectolitres in 1889, and a minimum of nearly 19,000,000 hectolitres in 1890.

A further supply was obtained by provisional works from the river Schwarza, varying from a maximum of 10,000,000 hectolitres in 1887 and 1889 to a minimum of nearly 2,000,000 hectolitres in 1890. Lastly, in the years 1889 and 1890, by the completion of a new conduit, water was procured from springs in the Höllenthal to the extent of 2,694,429 hectolitres in 1889, and 5,125,320 hectolitres in 1890. Details are given of the sizes of the reservoirs,

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length of mains, number of houses connected, public supplies, &c., for each year during the above period. The water is in all cases furnished by meter, for which a rent is paid in accordance with the diameter of the supply-pipe. The charge is a fixed sum to each house for each normal user, *i.e.*, a definite volume of 25 litres (5·5 gallons) per head, but no smaller supply than 5 hectolitres daily (110 gallons) per house is recognized. Special reductions are made for industrial supplies.

Complete chemical analyses are appended of the water from each of the above sources, as also of that from the reservoir on the Rosenhügel.

The total cost of the waterworks to the end of 1890 amounted to 26,216,442 gulden (£2,184,703), but of this sum no less than £1,192,122 was expended upon the construction of the aqueduct.

G. R. R.

The Works of the East Jersey Water Company for the Supply of Newark, N.J. By CLEMENS HERSCHEL, M. Inst. C.E.

(Advance proof, Journal of New England Waterworks Association, September, 1893.
12 Plates.)

These waterworks have been built with the object of supplying the city of Newark, eventually, with 50,000,000 gallons of pure water per diem, of which not more than 27,500,000 gallons are to be drawn by the city from May 1, 1892, until September, 1900, and the rest reserved meanwhile by the East Jersey Water Company for other purposes. The watershed of the Pequannok, a tributary of the Passaic river, at about 35 miles from Newark, was selected as the most suitable source of supply, and the works were undertaken under the guarantee of the Lehigh Valley Railway Company, which controlled the water rights, the contract price being six million dollars (£1,250,000).

Two storage reservoirs, the Oak Ridge and the Clinton, respectively 383 and 423 acres in extent, holding 2,555,000,000, and 3,518,000,000 gallons of water, and 836 and 992 feet above sea-level, supply the water by natural river-channels, 9 miles and 7 miles long, to the Macopin Intake Reservoir, at an elevation of 583·7 feet, with 12 acres of water-surface, and from thence the water is conveyed through a 48-inch steel conduit, 21 miles long, to the Belleville low-service distribution reservoir of the city of Newark, where the full water-level is at an elevation of 168·4 feet, although the conduit, which has a hydraulic gradient of 2 feet per thousand, reaches this point 190 feet above the level of the reservoir, and finally a smaller steel pipe, 36 inches in diameter, branches from the main conduit above this reservoir, and conveys water a further distance of 5 miles, to the South Orange-avenue high-service city distribution reservoir.

The object of the Macopin Intake, the capacity of which is 32,000,000 gallons, is merely to form a small reservoir, from which to pass the water conveniently into the steel conduit. For this purpose it is furnished with a gatehouse, which is provided with three sets of screens, four regulating sluice gates to control the flow of water from the screening chamber to the conduit chambers, and a cross-connection gate, by means of which the two separate conduit chambers may be connected. Only one conduit exists at present, but a second is contemplated at some future time.

The most novel feature of the whole work is the 48-inch steel conduit, a riveted boiler shell 21 miles long. Similar riveted pipes have been common in California for the past thirty years, but not in the Eastern States, and moreover the conduit of the East Jersey Water Company is larger in diameter than any hitherto built in California. It is true that riveted conduits 36 inches and 24 inches in diameter were built at Rochester, New York, in 1874, but they were made with cast-iron bell-and-spigot joints at every 56 feet, which obviates the necessity of manholes, and avoids raising the question of expansion joints; whereas one of the most startling features of the Californian conduits is the entire absence of any mechanical contrivance to take up expansion and contraction.

The experience of three winters has shown that no defect can be traced to the absence of such appliances on the East Jersey conduit, which has meanwhile been repeatedly filled and emptied and tested during severely cold weather, with variations of temperature up to 45° Fahrenheit. There is, however, a self-acting adjustment of the forces produced in the body of the conduit by changes of temperature, which consists in making all the circular joints and other appurtenances strong enough to resist the tensile strains due to an assumed variation of 45° Fahrenheit. And all stop-gates set in line of the conduit must have flanges and bodies sufficiently strong to resist such a strain. There are, on the 48-inch conduit, nine 48-inch shut-off valves, or gates, and on the 36-inch conduit two shut-off valves, besides five 16-inch gates at the junction of the 48-inch and 36-inch pipes. The 48-inch valves are vertical, with two 10-inch by-passes, and are inclosed in little brick houses, forming, at the same time, tool-houses and dépôts of supplies along the line; the 36-inch valves are horizontal valves, with 10-inch by-passes, inclosed in underground vaults. The valve-gear is so interlocked with the gear of a blow-off valve that the shut-off valve cannot be closed until the blow-off valve has first been opened, and the blow-off valve cannot be shut again until the shut-off valve has again been opened.

It should be mentioned that the conduit has been designed and proportioned to resist the pressures due to the hydraulic gradient only, in contradistinction to those which would be produced by a hydrostatic head, by which arrangement a saving is effected of fully 40 per cent. in the weight and cost of the pipe. To carry it

out in practice it is only necessary to regulate the quantity flowing through the pipe by a sluice-gate, placed at the up-stream end thereof, instead of by such a gate placed, as is usually done, at its down-stream end. For the purpose of letting air out of the pipe while being filled with water, or letting it in again when the pipe is drawn, clusters of special automatic air-valves have been fitted to the conduit, which are described in the Paper. Blow-offs are provided at all depressions, and man-holes at proper distances.

Four Venturi water-meters, a type which the Author strongly recommends, have been placed on the line; the 48-inch Venturi meter will pass 25,000,000 gallons of water per diem, with a loss of head, due to passing the meter, of only 4 inches of water column.

The conduit is made of open-hearth steel of very superior quality, the plates being $\frac{1}{16}$, $\frac{1}{8}$, and $\frac{3}{16}$ inch in thickness, this high quality having been chosen in order to leave no doubt as to the expediency of punching the plates instead of drilling, or of punching and reaming them. Bessemer plates would have cost £17,000 less, but probably no £17,000 spent on the works were better invested. In order to insure the preservation of the metal from rust great pains were taken to get the plates from the rolling-mill to the pipe-shop in a clean and bright condition, with which view special cars were made, and kept constantly running to and from the mills, both loading and unloading being done under cover. The sheets, as received, were punched by gang-punches, bevel-planed on the edges, rolled into cylinders, riveted by hydraulic riveters, caulked with the pneumatic caulker, and then twice dipped in distilled asphalt containing 98 per cent. of pure bitumen. The method of laying the pipes is described with much detail.

The telephone played as important a part in the construction of these works as it now does in their operation; a line was laid by the company to the several reservoirs, and an instrument moved along from time to time, keeping pace with the progress of the works. The Author frequently sat down on the ground in some field, or wood, along the line, called up his office in New York, had the stenographer read him his morning's mail, dictated the replies thereto, called up other parts of the work, or called up two or three foremen on the line for a simultaneous consultation by wire; and they and the engineer corps habitually did the same thing, so that it can readily be seen how the telephone contributed to the speed with which the whole work, stretched over 35 miles in length, could be carried on. For the filling or emptying of the conduit, and generally for the conduct of hydraulic operations on the pipe-line, the telephone has shown itself invaluable.

O. C. D. R.

Flood-Waves in Sewers and their Automatic Measurement.

By ALVA J. GROVER.

(Transactions of the American Society of Civil Engineers, 1893, p. 1.)

The experiments recorded were carried out by the Author at Omaha, Nebraska, during the past autumn, in a circular sewer 8 feet 6 inches in diameter, and at an invert depth of about 20 feet. The apparatus devised and fitted up comprised a rain-gauge—a somewhat modified form of the standard United States Weather Bureau pattern—and a sewer-gauge and storm-shield. The sewer-gauge itself consists of a galvanized iron boat 3 feet long, 1 foot wide, and 6 inches deep, held by a radial arm 7 feet 5 inches long and attached to the soffit at the manhole, and carrying on a $\frac{1}{2}$ -inch steel shaft a pair of 18-inch diameter iron paddle-wheels. By suitable gearing the motion of the wheels is communicated to a shaft carrying an electric key, which revolves once to every 2,046 revolutions of the paddles, i.e., a travel of 9,641.57 feet of the periphery. This key raises a small pin, and the motion is transferred to a glass pen working on the face of a revolving cylinder, on which the diagrams are traced. The gauge-boat is protected from damage by floating objects, and in flood-time by a wooden storm-shield securely hinged to the arch of the sewer. In time of full flood of the sewer, when the shield is carried up to its highest point, the gauge is still protected and clears the soffit, the paddles being just sufficiently exposed to act with the flood-wave.

When the apparatus was completed, it was used to test the flow in several rainfalls. In one case, the normal velocity recorded commenced at 1.45 foot per second, varying two hours later to 1.56 foot per second. The rainfall commencing, the velocity forty minutes later, with a depth of 32 inches, was 11.93 feet per second; thirteen minutes later the depth was increased to 52 inches, and the velocity to 13.36 feet per second; the next thirteen minutes indicated the same depth, but a reduced velocity of 12.9 feet, from which point the velocity diminished. The velocity of 13.36 feet per second marks, approximately, the crest of the wave; and this case apparently showed that the summit of the flood-wave reached the outlet of the sewer about the time the rain ceased. The registered rainfall on this occasion was 0.32 inch, and the percentage discharged was 60.6. By the United States Weather Bureau register, the duration of the rainfall was two hours fifty-five minutes, but the duration of disturbance in the sewer extended to six hours twenty-one minutes.

P. W. B.

The Basis of the Hygienic Value of Water.

By Prof. Dr. MAX GRUBER.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1893, p. 415.)

Among the most frequent matters upon which the expert in sanitary science is called upon to pronounce an opinion is respecting the probability that water derived from a given source may be used for drinking and domestic purposes without any danger to health. It is universally admitted that infected water may be the means of introducing disease-germs into the system, but the Author considers that the grounds upon which sanitary authorities base their verdict concerning the harmlessness, or otherwise, of any named water-supply should be clearly defined. A right answer to a question of this kind must not only apply to the present state of any such sample of water, but it should take into consideration also the possibility of future dangers, other than those due to malice, which might arise after a lengthened period of use. This aspect of the problem has not hitherto been made sufficiently clear, for if such had been the case, reliance would not have been placed, as it too frequently is, upon compliance with a few chemical and bacteriological tests, without any inquiry into the probable derivation of the supply. It is imperatively necessary that, before coming to a conclusion, the sanitarian should know the actual source of the water, and the chances of its accidental pollution, and he should ascertain whether, by the exercise of proper precautions in the future, it may be guaranteed an immunity from all suspicion. It is true that in many cases it is extremely easy to arrive at such an opinion, as for instance when the water is procured from rivers, lakes, or open wells, which are all of them exposed to possible pollution and thus cannot be preserved from contamination. Such water should therefore never be employed without special cleansing, even if the chemical and other tests indicate its absolute purity for the time being.

It is a well-known fact also that earth has the power of retaining and destroying many poisonous and injurious compounds, more especially the nitrogenous and organic products of decomposition, and that it acts as a filter in intercepting germs; water, therefore, which has passed through the soil is looked upon favourably for drinking purposes, whether it is procured artificially or issues naturally as a spring. Such water is not, however, at all times free from danger, but it is exposed to evils of two kinds which must be taken into account; for either the soil may for some reason or other not permanently act as a filtering material in the manner expected, and may fail to keep back infectious germs, or the pure water issuing from the sub-soil may become mixed with polluted surface-water, penetrating the upper layers of the soil, which are often filled with impurities, and in

either way the otherwise wholesome water may become injurious to health. The Author describes the various methods in which evils due to the above causes may arise, and asserts that no water can be reported upon favourably until these points have been systematically investigated. Neither chemical nor bacteriological analyses will serve as a substitute for these inquiries, though they may, in various ways, assist in forming an opinion. Water analysis is in fact only of use in directing attention to matters which cannot be detected in other ways by local observation. A knowledge of the chemical composition of the water is of importance, because substances may be dissolved in it which render it nauseous or ill-adapted for various uses; and further, because the dissolved impurities may indicate that such water has passed through layers of soil impregnated with human or animal excreta or the refuse from factories. It is, of course, necessary for the above analysis to procure a sample of the water fresh as it issues from the earth, and the condition of the water as it stands in the well or the spring-basin can have but little interest. In a similar way the bacteriological character of the water may convey useful information. The opinion that the number of germs present in a cubic centimetre has any immediate sanitary bearing has long since passed away; the view, also, that the saprophytes capable of liquefying gelatine are more deleterious than others is likewise obsolete. There is, in fact, no proof that the bacteria which accompany the process of decomposition and which need for their propagation the presence of air and a temperature approaching blood-heat are more to be dreaded than others. The fact may therefore be regarded as of trifling importance whether the water contains many or few micro-organisms of one kind or another, and it is well known that water when standing in a well becomes richer in germs the longer it stands. There is not even any strongly defined connection between the chemical composition of a given sample of water and the rapidity of the numerical increase in the bacteria it may contain.

The bacteriological examination of the water is of value, mainly as furnishing an indication of the action of the soil as a filtering material, and as concerning the yield of the natural filter represented by the sub-soil. This system of analysis, which was at first so highly vaunted, has come to be denied the undoubted value it possesses. The soil, as regards its upper layers, teems with germs of widely differing kinds; the water passing through it must become impregnated with these organisms. If notwithstanding this fact the deep well-water is found to be germ-free, it must be assumed that the lower layers of the soil have acted as a sufficient filter and have intercepted these germs, and it may therefore also be assumed that the soil would be capable of removing any disease germs carried down below its surface. Again, in a contrary sense, it holds good that if a sample of water is found to be rich in germs it may be possible for pathogenic germs to gain admission to it. Owing to various difficulties alluded to by the Author, there are

many obstacles in the way of arriving at any definite conclusions based upon these results. The counting of the germs in the case of spring-waters affords a useful index of purity, but it is not so with wells. Some authors have laid down the maximum number of germs per cubic centimetre which may be allowed in the latter; thus Fränkel was of the opinion that up to two hundred and fifty germs per cubic centimetre might be permissible. Plagge and Proskauer assumed three hundred, and Emmerich and Trillich appear to fix the limit at two hundred. Attention is directed to the fact that the numbers of bacteria present in a well fluctuate widely and depend somewhat upon the amount of water withdrawn. It is very necessary to obtain the water in an unmixed form; *i.e.*, in the state in which it percolates the soil, and various methods of doing this are discussed. Another matter which requires attention is the number of different varieties of bacteria found to exist in the water. It has been ascertained that water guarded from all kinds of impurities contains fewer species of bacteria than polluted supplies, but the enumeration of these varieties presents many difficulties. Some colonies will not grow in gelatine; some need a high temperature for their development; upon others the nature of the gelatine itself, whether alkaline or otherwise, has a most important bearing. Again, there is an enormous difference in the amount of time needed for certain species to come to maturity. The Author states that on this account, under the present plan of counting the colonies, only those results are really comparative which have been obtained at uniform temperatures and extending over similar periods of time. Even if it could be taken for granted that a water to be unobjectionable must contain but few varieties of bacteria, it is not now possible to determine how many species may be allowed in a given sample, whether five, ten, or twenty; and limits of this kind if imposed would lead to the rejection of nine-tenths of the existing supplies.

After quoting many recent opinions, the Author concludes that the bacteriological examination of well-waters, as now conducted, should be given up, because it establishes nothing, and is in many respects misleading. It may be taken for granted that at a depth of from 3 to 4 metres the soil is free from germs, and samples of water obtained with the observance of due precautions from deep wells should, he considers, be devoid of germs. The matters of real importance are, as already stated, clear and accurate observations respecting the derivation of the supply and its immunity from any possible pollution by excrementitious substances.

G. R. R.

Water-filtration and Cholera. By Prof. R. KOCH.

(Zeitschrift für Hygiene, vol. xiv., p. 393.)

It is now universally admitted that water plays a most important part in the conveyance of cholera germs; it is not, as some have asserted, the only vehicle for the spread of the disease, for, as the Author has pointed out, it is possible that cholera may be conveyed directly from one individual to the other, but in the case of indirect contagion in epidemics and extensive outbreaks of the disease where several vehicles may be concerned, water is no doubt the principal factor. Attention is directed to one of the most recent cholera epidemics, which, during last year, invaded the three towns of Hamburg, Altona, and Wandsbeck, and which throws a most important light upon this subject. These three towns lie so near together that, for practical purposes, they may be regarded as one; they differ but little in their general external circumstances, but their water-supply is distinct. Even the sources of the supply are different, for Wandsbeck obtains filtered water from a lake not exposed in any way to excrementitious pollution; the Hamburg water is derived in an unfiltered condition from the Elbe, at a point above the town, and the water of Altona, which is taken from the Elbe below the town, is filtered before use.

Hamburg, as it is well known, suffered terribly from cholera; Wandsbeck and Altona, except for the existence of certain imported cases, remained wholly exempt from it. At the boundary between Hamburg and Altona the state of things was most remarkable; the disease raged up to the border line and there made a dead halt. In the case of one street, which for some considerable distance formed the boundary, cholera was very prevalent on the Hamburg side of the street, while the Altona side remained free from it.

Here was an experiment carried out upon more than one hundred thousand inhabitants, which, in spite of its enormous scale, compares in the directness of its results with an exact and conclusive laboratory experiment. In two great centres of population all things were alike except the water-supply; in the one, drinking unfiltered Elbe water, the cholera raged severely; in the other, using filtered water from the Elbe, the cases were proportionately few; and moreover, the river-water supplied to Hamburg was comparatively but little polluted, whereas the Altona water was drawn from a point lower down the stream, where the Elbe had received the entire solid and liquid dejections of a population verging on eight hundred thousand persons. The Author shows that all the conditions and results agree with the principles laid down by bacteriologists, and clearly demonstrate that pathogenic germs can be removed by careful sand-filtration.

The working of the filter is discussed and the necessity for the deposition of a superficial skin of fine particles of mud and

organic matter above the sand in the beds is insisted upon. A filter-bed in good condition should not leave more than one hundred germs per cubic centimetre in the filtrate, however impure the water may have been originally, but the slightest disturbance in the filtering process leads to a great increase in the percentage of bacteria passing through the filter. Most of these germs represent harmless species existing in the sand and gravel, constituting the filter-bed itself, but some few are no doubt derived from the unfiltered water.

During the time of the above cholera outbreak the beds at the Altona waterworks were never worked at a greater speed than 100 millimetres per hour, and to this precaution was due the immunity from disease. In illustration of the evils likely to be caused by imperfect filtration an account is given of the waterworks at the penal establishment of Nietleben, near Halle, where a cholera epidemic recently occurred. Here, owing to too great a speed of working and sundry other causes, the water of the Saale, which in the raw state contained three hundred and two thousand four hundred germs per cubic centimetre, was found, after being filtered, to contain fifty-two thousand four hundred and ten germs, pointing to a defective filtering process. A pollution of the Saale by a tributary stream, joining it only 50 paces above the intake of the Nietleben works, took place, and an outbreak of cholera arose which probably might have been avoided, as it proved in the case of Altona, had the working of the filter-beds been reliable.

An account follows of certain cholera cases at Altona, subsequent to the above period, and their origin is discussed. Statistics are given of previous epidemics in Altona, some of them being such as to cause suspicion to be attached to the water-supply. These were mostly outbreaks of typhoid fever, which, as a rule, occurred several weeks later than those in Hamburg. In consequence of the epidemic at Hamburg in 1892, very great attention was paid to the bacteriological examination of the Altona filtered water, and analyses of samples taken almost every day were made by Mr. Weisser. Certain of these results obtained are set forth in a table. It was ascertained that one of the separate beds was working badly, as the number of germs rose rapidly in December, 1892, reached one thousand five hundred and sixteen per cubic centimetre on the 12th of January, and after falling a while, rose again in the last week of January to from one thousand two hundred to one thousand four hundred. In the case of open beds like those of the Stralau works at Berlin, liable to be frozen over in winter, similar disturbances, due to ice, can scarcely be avoided. Happily these derangements, to which all water works are exposed, have not always been followed by epidemics, because it needs the simultaneous presence of infectious germs in the raw material to cause such a misfortune. It is shown by statistics that the infected water of the Elbe, in which cholera-germs had actually been found, imperfectly filtered, as already described, at Altona in the winter

of 1892, probably caused a subsequent outbreak of cholera in Altona in the first two months of the present year. The danger of relying upon filtration for the removal of pathogenic germs is therefore insisted upon, and the Author lays down a series of rules to ensure the regular and proper working of the beds. He points out also the need of securing, if possible, an unpolluted raw material like the underground water from springs and deep wells.

G. R. R.

Some Improvements in the Practice of Disinfection.

By Dr. R. TRAUOGT.

(Zeitschrift für Hygiene, 1893, p. 427.)

The cholera outbreak of 1892 has brought into prominence the question of the most certain, and at the same time, the easiest and most protective methods of disinfection. Many new substances have been introduced, for which special advantages are claimed, after their effects have been tested by means of laboratory experiments with a few pathogenic bacteria and the spores of anthrax; and their value for practical purposes is assumed to be in accordance with the success or otherwise of these tests. But these tests do not afford all the needful information, because numerous other questions arise in actual practice which are neglected in the laboratory. Thus the extravagant price of any such substance, its deleterious effects upon utensils and clothing, its poisonous nature, disagreeable smell, or many other similar properties, may prohibit its domestic use as a disinfectant in spite of its admitted value. The Author states that it would almost appear advisable to rely upon the old approved methods with steam, dilute corrosive sublimate, carbolic acid, milk of lime, &c., with the employment of which the public is familiar, rather than to adopt novelties which may cause mistakes and lead to confusion. There are, however, difficulties and obstacles in the way of using very poisonous matters, such as corrosive sublimate, and very evil-smelling liquids like carbolic acid, and even steam when employed with soiled linen is liable to cause permanent stains, and therefore the Author has attempted to find substitutes to which these objections do not apply. In lieu of sublimate and carbolic acid, he suggests the use of a dilute solution of peroxide of hydrogen which Gibier and others have shown to possess a very marked disinfecting action, even when diluted to the extent of 1 part in 50,000. It was found that cholera-bacilli were destroyed in five minutes in a solution containing 1 part of the peroxide of hydrogen in 10,000 parts of water; but the bacilli of typhoid fever needed an exposure of twenty-four hours to a solution of 1 part in 5,000. It was necessary to ascertain whether these dilute solutions were capable of retaining their strength for some days, and this the Author

investigated by means of tests which are here indicated. He also tried how far the liquid was poisonous, and he found that even 100 grams of a 5-per-cent. solution could be taken internally without injurious effect. The results of numerous practical trials are here recorded, and also bacteriological tests with anthrax spores and various other bacilli, which are set forth in a table. The Author concludes that a 1-per-cent. solution of peroxide of hydrogen may replace a 3-per-cent. solution of carbolic acid; but at the present time the former is three times the cost of the acid. Even a half-per-cent. solution of the peroxide of hydrogen is fatal to germs, if the exposure is slightly prolonged. The dilute solution of corrosive sublimate is no doubt considerably cheaper, but its use should, if possible, be avoided in consequence of its toxic properties. While these trials were in progress, an opportunity of testing the effect of the peroxide of hydrogen upon the bacilli of diphtheria, and an account is given of the successful character of these experiments.

A second substance of which the Author made trial was the trichloride of iodine, to which Riedel had previously drawn attention. This material has an extremely sharp irritating smell, which induces coughing and sneezing; it is readily soluble in water, and is best preserved in the form of a 5-per-cent. solution, which keeps well and has a strong but by no means unbearable smell of chlorine and iodine. Even a very dilute solution, as for instance, one of 1 per mille, preserves its disinfecting power intact for several days, though in course of time a chemical decomposition takes place. This substance is not poisonous, as the Author was able to demonstrate by practical observations upon hospital patients. Its effect upon disease-germs was very marked. The bacilli of typhoid fever, cholera and diphtheria were destroyed by a 1-per-cent. solution in one minute, and the two latter species of bacilli succumbed to a 1-per-mille solution in the same space of time, the typhoid bacilli needing five minutes' exposure to the more dilute solution. Practical tests of this solution were likewise made with the dejections of cholera patients with very successful results. The price of the 1-per-mille solution is stated to be about one quarter that of a 3-per-cent. solution of carbolic acid. A solution of soda was also tried, but the practical effect of this salt appears only to be due to the high temperature at which it is used.

For the treatment of soiled linen the Author employed a dilute solution of corrosive sublimate (1 to 2,000), to each litre of which, on the recommendation of Behring, 6 grams of common salt were added, and he ascertained by experiments, of which details are furnished, that excellent results are attained by this means.

G. R. R.

*The Influence of the Surface- and of the Subsoil-water of
Magdeburg upon Health.* By W. KREBS.

(Gesundheits-Ingenieur, 1893, p. 418.)

The Author calls attention to his report on the surface-water of Leipzig, in which he pointed out the possibility that the extraordinary limitation of the area of the outbreak of cholera in the dry season during 1873, was due to meteorological conditions, and he states that an examination of the water and health statistics of the city of Magdeburg indicates a similar state of things. The materials for an investigation of this character are abundant, so far as relates to the health point of view, and he has obtained the geological data from Professor Schreiber. The particulars for the hydrographic survey were obtained from several sources, and these enabled the Author to prepare an approximate chart, needing more ample details later to confirm its accuracy. No less than seven watercourses traverse this district and react, in conjunction with the network of sewers, upon the fluctuations in the level of the subsoil water. The position of the town in the western half of Germany, 200 kilometres (124 miles) from the sea-coast, is discussed. The water-supply, which has been derived for two hundred years from the Elbe, has been the subject of much complaint, and since the severe visitation of the cholera in 1873 the condition of the water-springs in the vicinity of the town has been systematically examined.

Professor Schreiber and others, who have made a study of this matter, have shown that the well-water is much polluted by infiltration. The wells in certain districts are, in fact, cisterns, which obtain their supply from the refuse water of the neighbourhood. By reference to a chart, the Author explains the levels of the surface-water in the different quarters of the town, while the death-rate of certain areas is indicated by cross shading. An imaginary section is also given from east to west through the neighbourhood, with lines to represent the inclination of the surface falling towards the Elbe, and the approximate level of the water in the subsoil. As the result of his researches, the Author indicates the region where the purest water will probably be found. He considers that, even if a suitable water for drinking and domestic purposes could be obtained by sinking, it would not be advisable to discard the use of Elbe water, for a thorough irrigation of the soil of certain districts with an abundance of fairly pure water is absolutely necessary to wash out the impurities which penetrate below the surface. Before all things, however, it is important to ascertain, by means of accurate measurements, the water-level in the various districts.

G. R. R.

Investigations into the Action of Peat-dust on Cholera-bacteria.

By A. STUTZER and R. BURRI.

(Zeitschrift für Hygiene, 1893, p. 453.)

Peat is now largely used as a deodorant in dry closets, and as a stable litter and bedding-material for cattle, and it is valued by agriculturists, after it has served these purposes, as a manure. Some questions were recently promulgated by the German Agricultural Society as to whether peat, employed in the above ways, was capable of destroying the germs of infectious diseases, more particularly those of cholera, whether particular varieties of peat were better adapted for this purpose than others, and whether the certainty of its action upon these germs could be increased, and its fatal effect thereon accelerated by the addition of other substances which should at any rate be not injurious and if possible advantageous to plant life. The Authors have endeavoured to furnish a reply to these questions as far as cholera-germs were concerned. A review is given of the opinions of previous writers, together with the results they obtained, and the Authors refer to their own previous researches published in 1890. For reasons they have already explained, it was found advisable to employ strongly alkaline nutritive gelatine, containing 0.30 per cent. of carbonate of soda. The bacteria with which the experiments were conducted were obtained from recent cholera cases in Altona and Hamburg. Two samples of peat were first used, of which analyses are given, and subsequently a third kind was procured, and experiments were made to test the contents of each in readily-soluble acid, as also to determine their absorptive capacity. Bacteriological analyses were likewise made to ascertain the numbers of bacteria present in each sample. Sterilized and non-sterilized peat were introduced into a twenty-four hours old cholera-peptone-culture under proper precautions, and in every case, without exception, the cholera-bacteria were entirely destroyed in less than a quarter of an hour.

A second series of experiments was instituted to test the action of free phosphoric acid, superphosphate, and precipitated phosphate upon cholera-bacteria. The results, which are given in a tabulated form, seem to prove that, apart from its acidity, phosphoric acid and its compounds have no specific action upon cholera germs. Trials were likewise made of kainit, calcic-sulphate, and of a material consisting of calcic-sulphate, with a considerable admixture of phosphates; these latter, also, with the exception of the last-named compound, may be designated as inert. A fourth set of investigations relate to the effect of free sulphuric acid, hydrochloric acid, acetic acid, ammonia, and carbonate of ammonia, upon the vitality of the germs, with the result that the free acids of mineral and organic origin were found to have a powerful controlling action upon the development of cholera-bacteria. The action of acetic acid was indeed

most marked, and a solution so dilute as to contain but 0·05 per cent. of acid was immediately fatal to these bacteria. The action of carbonate of ammonia was likewise most surprising, as, when present in moderate amount, it undoubtedly stimulated the development of the bacteria, and as it is found in practice that the decomposition of fecal matters and urine gives rise to the production of notable quantities of carbonate of ammonia, it is necessary, if the cholera-germs are to be destroyed, to get rid of this compound. Experiments were undertaken to test the effect upon cholera-bacteria of using tar-extracts and other antiseptic agents, and carbolic acid was employed, both in a state of purity and also as raw 60-per-cent. commercial acid. It was only in the latter form that it proved effective, and lysol was inferior in its action to the much cheaper raw carbolic acid. Kreolin, on the other hand, gave excellent results. The Authors also investigated the behaviour upon cholera-bacteria of peat mixed with various other substances which might intensify or diminish its destructive action. It had been previously ascertained that peat used alone, probably owing to the humic acid present therein, was very fatal to the cholera-germs. Fresh fæces have a faintly alkaline reaction and putrefying urine, as already seen, gives rise to the production of carbonate of ammonia, in consequence of the decomposition of the urea. These facts would tend to materially reduce the activity of the peat with which the excreta might be mixed, but acids used with the peat would increase its proved fatal effects upon cholera-bacteria. The bacteria found in fecal matters have in a similar degree to cholera-bacteria the power of flourishing in a strongly alkaline medium, but they differ from the latter in being unacted upon by peat. A series of experiments were made to test the effect of acids and disinfectants upon the bacilli present in fecal matters. Dilute sulphuric acid was found to have a more powerful action in destroying these germs than any other substance tested. It was found also by practical trials that the fecal-bacteria could rapidly change the same when mixed with urine into a very favourable medium for the development of cholera-germs; the only way to prevent this state of things was by rendering the fæces acid, a very small dose of dilute sulphuric acid or hydrochloric acid sufficed to stop the production of carbonate of ammonia. Investigations followed into the behaviour of cholera-bacteria present in fecal matters, alone and mixed with peat, both fresh and stale; also as to the influence upon the mixture of kainit, plaster of paris, hydrochloric acid, sulphuric acid, and phosphoric acid. The general conclusion is that it is imperatively necessary when peat is used along with excreta, to mix with the peat such a proportion of dilute acid as shall suffice to destroy not only the cholera-bacteria, but also those bacteria present in the compound, which are able to generate carbonate of ammonia from the urine.

G. R. R.

The New Slaughter-houses at Königsberg, East Prussia.

(Deutsche Bauzeitung, 1893, p. 210.)

After describing the unsatisfactory condition of slaughter-houses in Germany, twenty-five years ago, reference is made to the Acts of 1868, supplemented by that of 1881, whereby any communality deciding to erect and maintain a public slaughter-house, can forbid the slaughter of animals elsewhere in the district, or the sale of meat other than that of animals slaughtered in the said public slaughter-house, unless brought in from outside the district, in which case it must be subjected to the same examination as that of animals slaughtered in the district slaughter-house, the latter, however, being also subject to examination while alive.

In 1886 Königsberg decided to erect a public slaughter-house, and with a choice of three sites determined upon that lying to the south of the town on the Aweider Road, near the East Railway (Ostbahn) station; the available area being 99 acres (40 hectares).

Having regard to the climate, the system adopted was similar to that at Erfurt, Tilsit, &c., in which the whole of the processes are carried out in closed structures. The arrangement is based on the assumption of a maximum daily slaughter of one hundred head of cattle, four hundred calves and sheep and four hundred swine, the number of slaughtering days in the year being one hundred.

A small scale plan of the whole arrangement accompanies the Paper. The yard is entered from the public road, near the northern side, by a roadway of 65 feet 8 inches in breadth, which, after the dwellings of the principal officials, the restaurant, accommodation for dealers, &c., bounding its northern side are passed, widens out to about twice that width, and continues up to the western boundary. To the south of this road, at the western end of the yard, are two market-halls for cattle and market-halls for sheep, swine, &c., and at the eastern end are the slaughter-houses, &c., comprising: in the centre, the slaughter-hall for cattle, which is 138 feet long and 52 feet 6 inches broad, down the middle of which is a gangway of 13 feet 2 inches broad. The height to the eaves is 23 feet, the roof is in seven bays, each of 19 feet 8 inches span, resting on cast-iron columns; the walls on the inside are lined to a height of 6 feet 6 inches above floor-level with glazed bricks.

The slaughter-hall for sheep, &c., is 138 feet long and 69 feet broad; the arrangement is nearly similar to that of the slaughter-hall for cattle.

Connected with the above, by a covered way, is the slaughter-hall for swine, which is of the same dimensions as that for sheep, &c. Close to, but distinct from it, is the scalding-house (Brühhaus) 64 feet long and 60 feet 8 inches broad. The offal-washing house

is close to the slaughter-hall for cattle, and the refuse from this is got rid of through a shoot into the railway trucks below. The cooling-house has an area of 10,760 square feet, and is in two storeys, the lower being cellarage 10 feet high, and that above 14 feet 9 inches. The temperature maintained here varies from 36° to 43° Fahrenheit. At the south-eastern corner, isolated from the rest of the yard, is the slaughter-house for diseased animals and for horses.

The necessary supply of water which amounts to 220,100 gallons, for each slaughter-day, is obtained partly from a surface sand stratum in the immediate neighbourhood, and the remainder from the fortification moat, fed from the river Pregel. The water is raised by pumping to a tank of 66,030 gallons content, through which passes the boiler-house chimney, 148 feet high. The drainage from the yard passes into the town sewer system.

Immediately on the south of the yard are the sidings of the Southern Railway, and there is also a connection with the Eastern Railway. The cost of the whole arrangement, which is as yet only partly carried out, was estimated at £100,000 (2,000,000 marks).

D. G.

General Theory of the Steam-Engine, the Steam-Jacket, and Superheated Steam. By G. LELOUTRE.

(Mémoires et compte rendu de la Société des Ingénieurs Civils,
September 1892, p. 343.)

This memoir is based on three of the old trials made by Mr. Leloutre, in conjunction with Hirn and Hallauer, on the celebrated steam-engine with superheating at Logelbach. Doubts were felt by the Author, and expressed in this Paper, as to the leakages past the piston during the trials, which he considers proved by experiments. It is known that Hirn employed various pistons, presumably with the object of having them perfectly tight, and diminishing leakage, which was more likely in his opinion to occur with superheated than with saturated steam. But the Author also considers that the valves in the Logelbach engine were not quite tight, and that this double source of leakage might affect the results.

Of all the trials, two, those of the 25th August, 1870, and the 30th September, 1871, were in his opinion more exact and complete than the others. These he proceeds to discuss in detail, giving indicator diagrams taken by himself. Notwithstanding many arguments to the contrary, he considers that the steam as used by Hirn was dry. But to deduce from these experiments coefficients applying to the action of the walls, he finds it necessary to study the two following points:—I. Weight of steam

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condensed upon the cylinder walls during admission. II. Cooling of the cylinder during exhaust.

From these, after careful verifications, he succeeds in determining in the fourth chapter of his Paper the coefficient of condensation of the internal cylinder walls, and their special calorific capacity. To these two experimental coefficients he attaches great importance. The two first chapters are devoted to the demonstration of a certain number of new equations, and verification of the experimental results of a steam-engine trial. In the third he gives an analysis of the experiment, with superheated steam, of the 30th of September, 1871, and calls attention to the fact that the Logelbach engine could be worked with or without superheated steam. The analysis is based on the theory of superheated steam by Zeuner. The study of the coefficient of condensation and the internal calorific capacity of the walls leads to interesting results, namely, the determination of the thickness of the cylinder walls, in which the exchanges of heat take place between them and the steam. This thickness is calculated at about $\frac{1}{4}$ millimetre, which, according to the Author, is equivalent to saying that the absorption and restitution of the heat by the cylinder are practically instantaneous. Many engineers had already expressed the opinion that the exchanges of heat take place in an extremely small thickness of wall, a view which is confirmed by calculation of their calorific capacity. Hence the use of a new expression, "cooling during exhaust," a phenomenon which is a function of the internal surfaces of the cylinder walls, and their range of temperature.

In the fifth chapter the Author explains the principles upon which he proposes to establish a theory of the steam-engine, equally applicable whether a steam-jacket be used or not. During the Logelbach experiments one fact he considers had been lost sight of, namely, that the action of the steam-jacket is continuous throughout the stroke, and that the heat added by the jacket to the internal surfaces during expansion increases the power, by evaporating the water already condensed. The theory of the steam-engine with superheated steam is analysed in the sixth chapter. As the effect produced by an engine working with superheated steam resembles to a certain extent that of a steam-jacketed engine, the same general equations apply. The Author concludes with a comparison of the Logelbach engine working with superheated steam without jacket, with saturated steam with jacket, and with saturated steam and no jacket.

Having given a sketch of his work, the Author proceeds to treat the subject in detail, mostly from a theoretical point of view, illustrating his remarks largely by the help of formulas. The questions of leakage from the piston, throttling of the admission valve, retarded admission, and the clearance spaces, are first examined. The single-cylinder engine used during the trial had four valves, two for the steam and two for the exhaust. Drawings of the pistons and piston-rings are given in the original Paper. It

had formerly been supposed that the piston-leakage and the losses from retarded admission, though acknowledged, were so slight that they could be neglected, but the Author's researches led him to a different conclusion. To determine the amount of these losses it is necessary to consider the condensation in the cylinder during admission. This it is possible to calculate by means of a coefficient of condensation, representing the number of calories absorbed per square metre of condensation surface, for every degree difference of temperature between it and the steam. Thence may be deduced the special calorific capacity of the walls, or the number of thermal units required to raise a square metre of wall surface of unknown thickness, presumably very thin, one degree Centigrade in temperature. One method of avoiding condensation is by storing heat in the cylinder walls, all heat thus introduced diminishing the heat given up during condensation, and increasing the pressure in the cylinder. This may be done, 1st, by a steam jacket; 2nd, by compression of the exhaust steam; 3rd, by superheating. Neither the coefficient of condensation nor the calorific capacity of the walls can be determined without taking into account all the surfaces touched by the steam during admission. A considerable quantity of steam is often condensed in the long and badly-covered pipes. It is therefore the total heat given to the engine, or the heat leaving the steam-chests, not that coming from the boiler, which affords a true measure of the amount of available heat. The Author reckons the calorific capacity of superheated steam, at constant pressure, at 0.48.

Returning to the subject of piston-leakages in Hirn's trial of the 25th of August, 1870, with saturated steam, the Author calculates them during different parts of the stroke, as also the quantity of water present in the cylinder, and the exchanges of heat in the clearance spaces. The leakages were revealed by the indicator diagrams, and took place when there was a difference of pressure between the two faces of the piston. As to the tardy admission of the steam into the cylinder, he maintains that it could not fail to happen with the valves used in the Logelbach engine, and that it naturally affected the results.

It has been said that the cylinder-walls act as a condenser during admission, and as a boiler during expansion. In analysing the action of the metal walls on the steam, the Author finds occasion to criticise this well-known aphorism. He is of opinion that during admission, not only condensation, but also and simultaneously re-evaporation of the steam in the clearance spaces takes place. During the period of expansion the piston offers new and colder cylindrical surfaces to the steam, and fresh condensation occurs upon these surfaces as they are successively uncovered. At the same time the temperature of the steam and of the inner walls diminishes during the progress of the expansion, and there is thus, during expansion, simultaneous evaporation and condensation, the walls, he considers, being covered with water by the fall of temperature. The quantity of heat yielded by the

walls during this lowering of temperature can be calculated, if the special calorific capacity of the walls is known. At the end of the stroke the cylinder will have less water inside it than at the beginning. During the continual condensation and re-evaporation the mass of the steam will be cooled, and probably in a state of fog. Then all the water held in solution by the steam will be carried over into the condenser, swept away the moment the exhaust opens, and it is only this portion of moisture which will convey heat from the walls during exhaust. The total heat absorbed by the cylinder walls and the piston during admission is carefully calculated, and also their cooling during exhaust. This loss of heat is shown in the indicator diagrams given by the Author. They exhibit at the top a diminution in the area of work done, due, in his opinion, to the fact that all leakage, condensation and formation of mist or vapour, such as are known to take place during admission, correspond to an equivalent loss of work.

The next question is the physical condition of the steam left at exhaust in the clearance space. It was the argument, whether this steam were wet or dry, which gave rise to the famous controversy between Hirn and Zeuner. The weight of steam condensed in the pipes from the boiler to the steam-chest is also considered. An analysis of the trial of 25th August, 1870, with saturated steam, shows that the steam left in the clearance spaces contained no water. The Author, however, asserts that there is a considerable error in calculating the heat absorbed by the walls during admission. The trial of the 30th September, 1871, with superheated steam and prolonged expansion is next examined, with all the experimental data. With superheated steam there is no condensation of steam in the steam-pipes. What the Author calls the coefficient of condensation is treated in detail, as also the surfaces of condensation in the clearance spaces, and their temperatures during condensation and admission. The calorific capacity of the walls is calculated, as in the earlier experiments, and the thickness determined through which the exchanges of heat take place between the walls and the steam. The Author is of opinion that, though losses due to retarded admission may be traced in both trials, in the experiment of September, 1871, there was much less piston leakage.

All the points here touched upon, in considering the Logelbach trials, such as the quality of the steam in the valve-chest, piston-leakage, coefficient of condensation, clearance spaces and their surfaces, calorific capacity of the cylinder walls, &c., are, in the Author's opinion, necessary in any theory of the steam-engine. When he comes to consider the theory of the steam-jacket, other equations are required, because the heat transmitted by the jacket to the cylinder-walls during different parts of the stroke must be calculated. There is a certain period neglected by most writers, during which heat is added to the admission walls by the jacket during expansion. This gives occasion for a new coefficient

of "absorption by the walls under the influence of a jacket," varying according to the condition of the walls, whether they are dry or covered with moisture. If the case be imagined of a very efficient steam-jacket, which acts by causing the cylinder surfaces of admission and expansion to become dry before the end of expansion, a different effect will be produced upon the walls than when they are covered with moisture. The quantity of heat transmitted by the jacket to the dry walls is so small that it can be neglected. Heat transmission through the walls towards the end of expansion, if the steam be perfectly dry, is also very slight. There are two ways of supplying steam to the jacket—either through a separate pipe from the boiler, or by allowing the whole of the boiler-steam to circulate first in the jacket before passing to the cylinder. In either case there will be a considerable deposition of water in the jacket.

In considering a theory of the steam-engine working with superheated steam, the Author first calculates the theoretical economy due to superheating and the practical utility of applying it to engines having two or several cylinders. It is extremely desirable to diminish condensation during admission in these cases, and this constitutes the special benefit of superheating. Whatever tends towards this object is a gain, and hence it is advantageous to jacket not only the cylinders and covers, but the valve-chests. To compress the exhaust-steam is a method much advocated by the Author. But the supplementary heat brought into the cylinder by the superheated steam is the most valuable means of preventing condensation during admission.

The principal calculated and experimental results of three experiments on the Logelbach engine with (1) saturated steam without jacket; (2) saturated steam with jacket; (3) superheated steam without jacket, are summarized in a Table. From it the Author draws the conclusion that as far as the indicated HP. is concerned, the weight of steam in the engine, where superheating is used, is about the same as with saturated steam working with a steam-jacket. The same economical result is attained with either, the engine giving in both cases about 21 per cent. economy of steam or fuel, as compared with saturated steam and no jacket, but in other respects there is a considerable difference in the effect produced. Superheated steam presents several advantages over a steam-jacket, especially in reducing condensation during admission. The heat added to the steam and brought in with it naturally penetrates all the internal surfaces of the clearance spaces, heats the piston-rod and covers, and reaches the inmost recesses of the cylinder. But with a jacket this surface-heating is not so effectually obtained. During expansion the advantages are to a certain extent reversed, as the effect of the superheated steam ceases after admission.

The Author insists very strongly on the extent of the surfaces in the clearance spaces as affecting the economy of a steam-engine. It is usual to consider only the clearance volumes, and if they are

reduced 1 or 2 per cent. of the total cylinder volume the result attained is supposed to be satisfactory. This he considers a great mistake. It is the surfaces in the clearance spaces which have a special and very injurious effect upon the condensation, and therefore these should be reduced to a minimum instead of being needlessly increased by inequalities of surface and by bolts, nuts, &c. Even with steam-jackets certain parts of these surfaces cannot be reached, and the only remedy is to increase the compression of the exhaust-steam.

B. D.

Boiler-trials at the Municipal Factory of Bercy, Paris.

By L. DE THUNIMONT.

(Le Génie Civil, vol. xxiii., 1893, p. 141.)

This article describes a special boiler used at the above factory with the "Dulac" grate, and a comparative trial made of this boiler and another, similar in all respects, except that it had the ordinary grate.

The article first describes the sources of loss of heat in ordinary boilers, and the various plans attempted by inventors to reduce the loss. The essential feature of the Dulac boiler is that the firebars contain water-tubes in communication with the boiler. The tubes are of soft steel, and the firebars are cast on to the steel tubes. The grate is set at an angle such that the fuel as it consumes will descend by gravity. The grate is easily cleaned, and the bars are removable. Only sufficient air is admitted for complete combustion, and it is claimed that there is an almost complete absence of smoke.

The comparative trial above referred to gave the Dulac boiler a superiority of 11 per cent. in power, and 23 per cent. in economy of fuel. Mechanical stoking was used.

The article is fully illustrated.

C. F. F.

*Construction of a Power-House at the Genesee Falls,
Rochester, N.Y.* By ROBERT CARTWRIGHT.

(Transactions of the American Society of Civil Engineers, 1893, p. 19.)

The Genesee, draining an area of about 2,500 square miles, frequently pours over the falls at Rochester City in a volume nearly 300 feet in width, 5 to 6 feet deep, and with a vertical fall of about 90 feet. The total fall of the river within the city limits

is 257 feet. Its power is used for many factories, but especially for flour-mills.

The plant and power-house of the Rochester Power Company is erected immediately adjacent to the falls. The head-gates of the race are just above the Central Avenue dam, about 300 feet from the brink of the falls, and the power supplied amounts to about 1,200 HP. In some summer seasons very little water is available in the river, and a steam-engine is then used to supplement the work; but so treacherous is the river that it is frequently raised to half-flood within twenty-four hours.

The hydraulic plant consists of two double Leffel wheels, 26½ inches diameter, each supplied by a 5-foot flume or supply-pipe, and developing 600 HP. (each) under an effective head of 87 feet, and with a volume of 6,250 cubic feet of water. The wheels are made of phosphor-bronze, with buckets of tinned Otis steel. The power is transmitted to the upper line-shaft by a sixteen-coil endless 1½-inch Manila rope, with a hanging tension adjustment of about 30 feet, at a speed of 7,540 feet per minute. Since starting in November, 1891, the plant has been working daily without a single interruption.

Owing to the close proximity to the falls, it was impossible to erect an ordinary cofferdam for putting in the foundations, which are in a depth of about 11 feet of water; but as the rock overhung the base to a considerable extent, and it was deemed advisable to cut this away so as to batter slightly backwards, use was made of this by dropping all the material into the water until the accumulating mass reached a sufficient height above the water-surface. The pile of rock, backed in with cement in bags as required during the progress of the work, served its purpose during the low water of the summer months; and the whole was washed away during the following winter, the scour being such that blocks as large as two cubic yards were carried 200 feet down the stream.

P. W. B.

The Effect of Tuberculation on the Delivery of a 48-inch Water Main. By JAMES DUANE.

(Transactions of the American Society of Civil Engineers, 1893, p. 26.)

In 1880-81, the Author laid a 48-inch main for the purpose of diverting a portion of the flow of an aqueduct (the latter consisting, at the junction-point, of six parallel 48-inch cast-iron mains) into an old reservoir at Central Park, New York. The aqueduct pipes had been laid in full conformity with the most approved engineering conditions in all but one respect, viz., the castings had not been coated with coal-tar varnish, or with any other protective preparation. In making the new connection, and cutting

into the old main (or rather into one of the six pipes), the latter was found to be honeycombed or tuberculated throughout, although it had been laid only about seven years. All the tubercles were of the same general shape—roughly formed frustums of cones, with diameter of base equal to about two or three times the depth, and with roughly flattened tops. As a rule, the largest tubercles—about 2 to 3 inches base diameter and 1 inch deep—were at the bottom of the pipe, the size decreasing pretty uniformly up the sides to the crown, where the dimensions averaged about one-fourth of those previously described. So far as examined the whole of the six mains appeared to be similarly affected.

The usual formula was used by the Author in his calculations, viz., $V = C\sqrt{RI}$, where V = velocity in feet per second, C = the specific coefficient, R = hydraulic mean radius, and I = sine of angle of inclination. In the present case the value of C is taken at the average of general practice = 135.

The total flow of water was 96,000,000 gallons per diem; and deducting the supply to certain branch mains, and estimated proportion of leakage, the flow through each of the five pipes (*i.e.*, exclusive of the one interrupted), was about 18,500,000 gallons per diem.

The observed loss of head, however, was 3.39 feet, and the length being 5,992 feet, the value of C is only 96; about 30 per cent. less than the average.

After the completion of the connection of the new pipe with the old main, the whole length was tested; the length of the old tuberculated portion being 5,306 feet, and the new-coated main 4,123 feet—together 9,429 feet. The observed loss of head in the first section was 1.86 foot, while in the second it was only 0.74 foot. In other words, the value of I in the formula for the first portion was 0.00035, against 0.00018 for the second—practically double. Taking C at 96, the value above deduced, the flow through the first section would be 14,500,000 gallons per diem; and this same quantity flowing through the new length also gives the value of C in the latter = 134, which fully accords with ordinary practice.

An opportunity occurred quite recently of examining the new main, and it was found to be in substantially the same condition as when laid eleven years previously. The Author believes that in an uncoated main, the tuberculation will be fully developed in seven or eight years, but that after that time no further decay takes place; but that the discharging capacity is reduced by fully 30 per cent.

P. W. B.

Air-compressors of the Paris Compressed-air Company: Coal-Consumption Trials. By L. DE THUNIMONT.

(Le Génie Civil, vol. xxiii., 1893, p. 158.)

A description and drawings of these machines were published in the "Génie Civil" of May 21, 1892.¹ It need only be repeated here that there are four triple-expansion Corliss engines of 2,000 HP. each, with twenty Babcock and Wilcox boilers, furnished with Green's economisers, the whole made by Schneider and Co., of Creusot.

The specification prescribed as a maximum for coal-consumption on trial, 1·54 lb. per I.H.P. per hour, the fuel being briquettes from Anzin. The trial was specified to last eight hours, the speed to be 60 revolutions per minute, the steam-pressure on the smallest pistons about 150 lbs. per square inch, and the compressed air-pressure 114 lbs. per square inch. A deduction was to be made from the total consumption for condensation in the steam-pipes. The trials were made on the 19th of January, 1893. All observations and calculations were made in duplicate by independent engineers.

The eight-hours trial was divided into sixteen periods, and diagrams taken simultaneously from the three cylinders in the middle of each period. The springs of the indicators were tested before and after each diagram, and the diameters of the indicator-piston measured to the hundredth of a millimetre ($\frac{1}{2500}$ inch).

The condensation in the steam-pipes was ascertained by special experiments subsequently.

The results of the trials showed, for a total I.H.P. of 1,996, a consumption of 1·29 lb. per I.H.P. per hour.

Other experiments, made in December, 1891, on the efficiency of the machinery, to determine the ratio between the indicated work done by the air-pistons and the indicated work in the steam-cylinders, showed a ratio of 0·8997. The engines had then only been in use a few days.

The Author considers that, for reliability and economy, this machinery is superior to that made in other countries for a similar purpose.

C. F. F.

¹ Minutes of Proceedings Inst. C.E., vol. cix. p. 472.

On the Use of a Sliding-Joint in the Construction of Fly-wheels.

By F. CHAUDY.

(Mémoires et compte rendu des travaux de la Société des Ingénieurs Civils.
May, 1893, p. 614.)

Under the action of what is commonly called "centrifugal force," the rim of a fly-wheel is in a state of tension, and is therefore elongated. With the ordinary form of construction, in which there is a rigid connection between the spokes and the rim, the radius cannot increase at the ends of the spokes (except by the amount by which the spokes themselves extend). To obtain equal stress in all parts of the rim, it is necessary that the rim should be able to expand equally in all directions, retaining its circular form. For this reason, the Author proposes that the connection between the spokes and the rim should be a sliding connection, such as may be made by studs screwed into flanges on the ends of the spokes, and passing into smooth holes in the rim.

The Author also objects to the ordinary form of spoke when a rigid connection is used, because in that case the bending stresses are greatest at the end of the spoke, while the section is always made least at the end. With the sliding connection the usual tapered spoke is the correct form, there being no bending moment at the outer end.

A mathematical investigation is given of the stresses in the rim of a fly-wheel, both with sliding and with rigid connections to the spokes.

C. F. F.

A Proposed Uniform System of Screw-Threads for France.

Report of the Commission appointed by the Société d'Encouragement pour l'Industrie Nationale.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1893, p. 173.)

In France there is no standard system of screw-threads adopted in engineering construction, but the greatest diversity exists between the threads of screws having the same diameter. In the large military, naval, and railway workshops, special systems have been adopted, which, however, differ one from the other; so that it is very rare to find two screws of the same diameter (taken at random) having the same pitch and form of thread. The Commission was appointed by the Society to consider the best means of arriving at a uniform system of screw-threads.

The report contains details of the various systems of screw-threads in use,—Whitworth, Sellers, and eight special systems used in France, as well as some systems that have been from time to time proposed as standards.

In a form of screw-thread recommended for adoption as standard, ease of manufacture is of great importance. The form recommended has as its basis an equilateral triangle, whose side is equal to the pitch; one-eighth part of the height of the triangle being cut off at top and bottom, parallel to the axis of the screw. There are twenty principal sizes of screws, denoted by the numbers, 0, 1, 2, 3, ... 19.

The pitch of the screw p , the diameter of the screw D , and the width of the nut across the flats l in millimetres, are given by the formulas:—

$$p = \frac{n}{2} + 1$$

$$D = \frac{(n + 10)^2}{5} - 14$$

$$l = 3n + 5 + D.$$

The following Table gives the sizes of the principal screws; the number 0 (corresponding to $D = 6$ mm.), the inferior limit of the series, being the same as the superior limit in the Thury standard system in general use for watch and clock screws.

If a screw of intermediate diameter is required it should be expressed in millimetres by a whole number, and the pitch taken the same as that of the principal screw of immediately smaller diameter.

n.	p.		D.		l.	
	Mm.	Ins.	Mm.	Ins.	Mm.	Ins.
0	1.0	0.04	6	0.24	10	0.39
1	1.5	0.06	10	0.39	20	0.79
2	2.0	0.08	15	0.59	25	0.98
3	2.5	0.10	20	0.79	35	1.37
4	3.0	0.12	25	0.98	40	1.58
5	3.5	0.14	31	1.22	50	1.97
6	4.0	0.16	37	1.46	60	2.36
7	4.5	0.18	44	1.73	70	2.76
8	5.0	0.20	51	2.01	80	3.15
9	5.5	0.22	58	2.28	90	3.54
10	6.0	0.24	66	2.60	100	3.94
11	6.5	0.26	74	2.91	110	4.33
12	7.0	0.28	83	3.27	125	4.92
13	7.5	0.30	92	3.62	135	5.31
14	8.0	0.31	101	3.98	150	5.90
15	8.5	0.33	111	4.37	160	6.30
16	9.0	0.35	121	4.76	175	6.89
17	9.5	0.37	132	5.20	190	7.48
18	10.0	0.39	143	5.63	200	7.88
19	10.5	0.41	154	6.06	215	8.46

A memoir by Mr. Marre, of the firm Bariquand and Marre, on the "Manufacture of Triangular Screw-Threads" is appended to

the report. A tool and holder is described, the arrangement being such that the form of the thread produced is not altered by grinding the tool.

A note on the unification of screw-gauges is appended. This note gives tables of the principal gauges used in England, America and France.

The Commission recommend that five thousand copies of their report be distributed among persons interested in the subject—engineers of the State, technical societies, railway and shipping companies, &c.—with a view to elicit a general discussion, and prepare the way for the adoption of a uniform system.

A. S.

Weidknecht's New Radial Axle for Locomotives.

By AMÉDÉE LALANCE.

(Le Génie Civil, vol. xxiii., 1893, p. 70.)

The object of this invention is to enable a large boiler and fire-box to be carried by an engine whose rigid wheel-base is limited to a small dimension by the necessity of passing curves of small radius. When the railway, as in such a case is most common, is of narrow gauge and has steep gradients, the difficulty of providing a large enough boiler is all the more serious.

The system of Mr. Weidknecht consists in hinging the axle-boxes of the radial axle to the frame by means of a short link on each axle-box. This link has a spherical joint with the frame to provide for vertical play, and is linked to the axle-box of the radial axle by a vertical pin. The load is borne by the axle-box through a sliding contact and the usual laminated springs. There are no horn-plates, the above mentioned links alone controlling the movements of the axle, which is thus free to set itself radially to the curve without any relation to the position of the driving wheels.

Ten locomotives of this type have been built for the railway company of La Drôme of a weight of 23 tons and a tractive power of 4 tons. They are six-coupled, metre-gauge, the radial axle carrying 3·2 tons. The driving-wheels are 2 feet 6 inches in diameter, and the trailing-wheels (radial) are 2 feet. The article is fully illustrated by a two-page plate and nine figures in the text.

C. F. F.

Forging-Presses. By C. DUFOUR, Mining Engineer.

(Bulletin de la Société de l'Industrie Minérale, vol. vi. 1892, p. 1037.)

Following a preliminary classification of the various forging-presses, the Author describes and criticises the working of Tannett, Walker and Co.'s machine with high-pressure weighted accumulator; the Bochum press with high-pressure accumulators operated by compressed-air, on the Prött and Seelhoff system; the Davy press, in which the hydraulic power is supplied by three single-acting horizontal rams, driven by a double-cylindere steam-engine without fly-wheel; W. D. Allen's press, constructed by Galloway, and used at Bessemer and Co.'s works, a contrivance fully described by the inventor at a meeting of the Iron and Steel Institute, and in the *Revue Industrielle* of the 19th of December, 1891; and Breuer, Schumacher and Co.'s press, which differs considerably from all the preceding varieties in having no steam-engine or pumps, the plant consisting of the press proper and the compressor. The Author gives figures showing the consumption of steam in the various presses, and some useful information as to rapidity of movement and regulation of speed; remarking that, when finished work is required to be done by small presses, it can only be economically performed when done rapidly. In all cases rapidity is necessary, so as to keep the number of heats at a minimum. The only obstacle to rapid work arises from the travelling-carriage generally employed in the manipulation of the ingot, which will, the Author thinks, be replaced in the majority of cases by more suitable systems. More important than rapidity of impression is the power of varying the speed promptly, so as to obtain as slow a motion as may at any time be desired. Presses should be very solidly built in all parts, and should be of as simple construction as possible, the number of valves, in hydraulic presses, being kept as small as practicable.

Comparing the press with the steam-hammer, the Author observes that the latter possesses the advantages of being a much simpler construction than the majority of presses, and of requiring only a small amount of repairs—advantages which are more especially marked when the hammer is compared with presses requiring engines and pumps. On the other hand, the work done by the press is far more accurate, the foundations required are insignificant; no destructive vibrations are caused, as in the case of the hammer; the ingots may be worked colder, and consequently the number of heats diminished, without risk of breakages. The useful effect of the hammer is never more than a fraction of the theoretical effect, because of the elasticity of the blow; while, in the press, the force of the pressing-ram is transmitted in its entirety to the ingot.

The *modus operandi* of the two contrivances being quite different, it is natural to suppose that the results obtained are not identical. In the case of non-homogeneous metals, as, for example, iron, the

prevailing opinion is that the blow of the stamper is better adapted for the elimination of silicates than the slow action of the press. This is, however, not universally admitted; and there are certainly forges where iron is actually treated by press. In any case, the objection is daily losing its significance, owing to the rate at which iron is being replaced by steel. For all homogeneous metals, such as steel, the press is perfectly suitable. The press forges the metal to the core, while the hammer has a rather superficial action. The texture of ingots forged by the press is finer towards the centre; while, on the contrary, ingots forged by the steam-hammer have a poorer texture at the centre. When, therefore, the ingot is rather massive, the forging of the central part would be imperfectly done with the hammer. The press would thus be always preferable for pieces in which the central part is required to resist stresses. In the manufacture of cannon and similar pieces, defective forging at the centre is not a matter of such importance, since the core is removed by boring. The quality of forgings made by the two methods is almost identical when the most favourable cases of hammer-work are compared with the work of the press, but in all other cases that of the press is superior.

The Author quotes Gauthier's table of equivalent presses and stampers, but considers it more reasonable to determine the power which a press must have in order to accomplish certain work rather than to compare two appliances of which the *modus operandi* is so different; and he shows how such a determination may be made.

In the matter of relative cost of the two plants and of erection of same, the Author is unable to give exact figures; but he states that there is no great difference in purchase price between certain types of press and hammers of the same capacity; on the other hand, the foundations required for a press are insignificant, while those of a hammer of any large size entail considerable expenditure. In determining the net cost of the two forges, trials should be made at a works possessing a press and a hammer of the same capacity. According to Daelen, the press, with an equal expenditure of steam, would accomplish double the work of a hammer, independently of the consideration of speed; while Gauthier and Demenge estimate that the number of heats required with the press is reduced by one-half, and the time of work by four-fifths—the latter figure tending to show that the press is capable of doing five times as much work as the hammer in a given time. The Author considers this to be too high an estimate of the capacity of the press, and adduces figures from actual practice which indicate that the work done by the press is generally $2\frac{1}{2}$ times more than that of the hammer in the same period. With suitable travelling-carriages, the output of the press would be still greater than that of the hammer. Press installations are usually served by from four to six furnaces, hammers by from two to four.

The press is adapted for roughing-out ingots, forging, finishing, and beating-out. Finishing is very easily done by it, but is only effected with economy when the press is capable of dealing a large number of blows per minute. Forging, properly so called, is perhaps more accurately done by the press than by the hammer. At Whitworth's workshops all the forging is done by press; and the Author thinks that there is no doubt of its ultimate general adoption. Several firms have for some time past employed presses of moderate power for all kinds of railway-carriage work.

In conclusion, the Author observes that the greater the power required, the greater the advantage of the press, for, if it is desired to exceed powers from 100 to 150 tons with the hammer, extremely heavy foundations, sometimes impossible to build, are required; while, as already stated, the press requires nothing of the kind. The chief advantage of the press compared with the hammer is its larger productiveness, an important matter in times of industrial activity. The Author thinks that presses of medium size, suitable for all ordinary work, would be advantageously employed, adding that the general adoption of such presses has been retarded by reason of their high prices when the arrangement comprises engines, pumps, and high- or low-pressure accumulators. The manner in which this difficulty has been solved by the use of the compressor has shown that the question of cost entered in a novel way, and that this appliance presented real advantages, combining strength with pliancy. The Author is of opinion that the development of press installations of all powers is only a matter of time.

A. H. C.

The Oil-shale Industry in France and in Scotland.

By G. CHESNEAU, Ingénieur au Corps des Mines.

(Annales des Mines, vol. iii. 1893, p. 617.)

Prior to 1863, when American mineral oils began to appear in European markets, the French shale-oils used for lighting purposes, which had to compete only with vegetable oils, were never sold for less than 2s. 7d. to 2s. 9d. per gallon. From 1863 to 1871 American competition caused a rapid fall of price, first to 1s. 7d., then lower and lower, until to-day lamp-oil is delivered, barrel included, for 10½d. and even less per gallon. During the years specified, the only customs duty to which imported mineral oils were subject consisted in a tax of 5 per cent. *ad valorem*; and if, in spite of this insignificant duty, the home industry struggled successfully with foreign competition, it was only because during that period the middle price of refined petroleum was maintained

at 1s. 9d. per gallon in bond, or 1s. 9½d. inland (allowing for the 5 per cent. *ad valorem*), a figure still much higher than the actual value of American petroleum after payment of duty. Subsequent to 1871 the fall in the market price of petroleum was accelerated; but the customs dues, rose much above 5 per cent. *ad valorem* (till 1881 11d. per gallon for refined oil was reached, and from that date to 1892 8½d. per gallon), have just compensated the native industry for the drop in price of American and Russian petroleum, which has now fallen to 5½d. and even less per gallon, barrel included, before payment of duty; and these duties have alone permitted the French shale industry to make any progress. But this continued fall in the price of petroleum has of late years caused a movement in France in favour of reducing the duties on this article, duties which have become far higher than its value in the countries where it is produced. As in 1871, so now, the very existence of the French oil-shale industry is imperilled; and it behoves the public authorities to reconsider the situation and the amelioration, if any, of which it admits.

The Author was commissioned by the Minister of Commerce to study, in France and abroad, the condition of the mineral oil industry; and, in February, 1892, he investigated the manufacture of shale-oil in France and in England, making special inquiry how it was that an industry, so precarious in his own country, had made considerable advance in England without the advantage of protective duties.

In this report of his investigations, the Author deals first with the oil industry of Autun and of Buxières-les-Mines (in Allier), where the principal and only important deposits of bituminous shales in France occur, remarking in passing that, of 210,000 tons of shale produced in that country during the year 1890, the basins of Autun and Buxières contributed respectively 156,000 and 51,000 tons. After a brief geological account of these two deposits, the methods of distilling the shales and of rectifying the crude oils are described. The products of the distillation of 35·316 cubic feet (1 cubic metre) of crushed shale, weighing from 1 to 1½ ton, are stated to be as follows:—

Crude oil, density 0·890 to 0·902	9·90 to 12·76 gallons,
Ammoniacal liquor	11·00 „ 13·20 „
Gas	847·584 cubic feet,

the Autun shales yielding less than those of Buxières.

The machinery and methods employed at the refining works at Plamores (Buxières) and of those of the Société Lyonnaise at Saint-Léger (Autun) are described in some detail, the Author concluding this section with a consideration of the cost of production and the profits accruing. Assuming that the cost of 22 gallons (1 hectolitre) of crude oil is 8s., that the cost of refining this quantity, together with general expenses, amounts to 2s. 5d., and taking the mean selling prices of the different commercial oils as a basis of calculation, he finds that there is a net profit to the

refiners of 2s. 8½d. on the 22 gallons of crude oil, or, per gallon, about 1½d.; while, taking the lowest selling prices, the profit amounts to only ½d. per gallon of crude oil.

The Author then passes on to the Scotch industry, which produces annually, in round numbers, 52,000,000 gallons of crude oil from 2,000,000 tons of shale. The deposits occur in the counties of Mid and West-Lothian, and consist of beds of boghead—now nearly exhausted—and of bituminous shales, the latter occurring in four seams, of which, however, only one is usually exploited in each shaft. These bituminous shales are much richer in oil than those of Autun, yielding on an average 27 gallons of oil per ton as against only 11 gallons obtained from the French shales. Further, the French crude oil contains only from 2 to 3 per cent. of paraffin, while that of Scotland yields 12 per cent.; besides which the distillation of Scotch shale furnishes a considerable quantity of ammonia, which, transformed into sulphate, constitutes two-thirds of the value of the commercial products of the shale.

Notwithstanding the richness of these shales, the competition of American petroleum and paraffin, not burdened with import duties, has nearly ruined the Scotch industry, which, after enjoying remarkable prosperity between 1875 and 1885, has since rapidly declined. It has only succeeded in its struggle with American produce by continual perfecting of its methods of treatment, notably with a view to increasing the output of sulphate of ammonia—a product which has practically saved the Scotch oil and paraffin industry from collapse.

The Author shows, in a striking way, how the Scotch shale industry has suffered from American and Russian imports, by comparing to-day's selling prices with those of twenty years ago:—A gallon of lamp-oil, which was then worth, on an average, 1s. 5d., now realises only 5½d.; refined paraffin and crude paraffin, which were then worth 10d. and 5d. per lb. respectively, are now sold for as little as 5d. and 2½d.; heavy oil and sulphate of ammonia, which were sold for £20 per ton are now worth £5 and £10 per ton respectively. All the prices have thus fallen one-half, and some as much as two-thirds. By incessant improvements the cost of production has been reduced to such a point that the gallon of oil which twenty years ago cost 12·63d. to produce now costs only 4·44d. This figure is, nevertheless, higher than the selling price; and it is only the increased production of paraffin and sulphate of ammonia that has allowed the Scotch industry to exist.

The Author describes the methods of mining the Scotch shales and of distilling them for crude oil, noting, under the latter head, that the average produce amounts to 27 gallons of crude oil per ton of shale, while the cost of distillation (not including general expenses) averages 2s. 9d. per ton, which, added to the cost of the shale, namely 5s. 6d., makes the cost of production of 27 gallons of crude oil 8s. 3d., or of one gallon, 3·66d. The methods of rectifying the crude oil, of separating the paraffin, and of producing sulphate of ammonia are then described, the Author showing that the cost

of the complete treatment of a ton of shale amounts to 12*s.* 7*d.*, the average selling price of the products to 13*s.* 7½*d.* per ton of shale, leaving a profit of 1*s.* 0½*d.* per ton to the refiners.

Comparing the French and Scotch industries, the Author shows that, in regard to mining methods, the comparison is entirely favourable to France, the cost of winning shale in Scotland being 5*s.* 6*d.* per ton, and in France only from 2*s.* 9½*d.* to 3*s.* 2½*d.* (according to its density) per ton, the latter being a very moderate cost, which can hardly be reduced. The Author sees nothing in the Scotch rectification processes worthy of imitation by his countrymen, except in the matter of the employment of superheated steam, which is always advantageous in the fractional distillation of oils not very rich in illuminating properties. The method is also used in the Russian refineries of crude petroleum. It is quite another thing with the processes of shale-distillation for crude oil, which are absolutely characteristic of the Scotch industry. In the Scotch method of treatment, superheated steam is injected in large quantity into the mass of shale, which is gradually heated up from a low temperature at the introduction of the charge at the top of the retort to a white-red heat at the bottom of the fire-brick chamber, a temperature unattainable in the French retorts. Messrs. Chosson and Tournaire have already shown that the presence of water in shales, up to a certain point, favours the formation of oils; and, without wishing to make it appear that French shales would in Scotch distilleries give a yield comparable with that of English shales—which are far richer in bituminous matter—the Author thinks that it is reasonable to conclude, from the experiments of these gentlemen, and from the results obtained in Scotland, that a progressive distillation finishing at a very high temperature would considerably increase the yield of the shales of Buxières and Autun. The Author has himself endeavoured to determine the part played by steam by distilling Buxières shale in sandstone retorts of a litre capacity, first, without, and, secondly, with the injection of superheated steam, obtaining in the latter way 50 per cent. more crude oil than in the former, the density of the oil in the first case being 0.973 (at 14° Centigrade), and, in the second, 0.955. Nothing more can be inferred from these experiments than the general effect of the introduction of steam; for the distillation of French shales in Scotch furnaces would alone indicate whether the increase of yield would justify the very costly alterations which the adoption of the system would involve, alterations which, if the residue could no longer be utilized, as at present, for heating the retorts, would necessitate the use of a special fuel in the gas-generators, the consumption in which might, however, be reduced, as in Scotland, by utilizing the combustible gases at present hardly anywhere made use of in the French shale industry. Other determining considerations would be the probable increase in the yield of ammonia, and the content of paraffin, which would allow of the extraction of those substances; also a certain improvement

in the quality of the crude oil, which is less odorous when the distillation of the shale is effected in presence of steam.

The Author, in conclusion, suggests that the French shale-oils, which are rather highly sulphuretted, might with advantage be freed from sulphur by the oxide of copper method used in America in the treatment of Lima oils.

A. H. C.

Outbursts of Carbonic Acid in the Rochebelle Mines (France).

By C. LANGE, Chief Engineer of the Rochebelle Collieries.

(Bulletin de la Société de l'Industrie Minérale, vol. vi. 1892, p. 1141.)

The Author recounts the several accidents which have occurred in the Rochebelle collieries during the years from 1879 to 1889, owing to outbursts of carbonic acid gas, concluding his Paper with some general observations, which may be useful to those who have to contend with similar difficulties.

In almost every instance of disengagement of this gas which the Author has observed, there have been precursory symptoms, indications apparently of no importance, which have not been understood at the time, but of which a perfectly clear account has been given after the accident. The Author has noticed that, at the approach of certain outbursts, low rumbling detonations were of more frequent occurrence than at ordinary times; that the atmosphere of the workings became heavier; that there was pressure at the mouths of the mine; that lamellæ of coal fell away from the seam with decrepitation; that changes were generally produced in the physical condition of the coal; that almost all the outbursts occurred in the vicinity of irregular ground; and that there was reason for mistrusting a coal which passed from hard to friable, and which assumed an earthy appearance—generally the coal of areas disturbed by faults, swellings, or nips.

Increased precautions were necessary during the passage of these irregularities.

The intensity of the outbursts in a particular seam, in the vicinity of disturbances, depends on the depth. The Author has not verified a single disengagement of carbonic acid at the 410 feet level in No. 1 seam of the Rochebelle colliery, while two such outbursts have already occurred in the same seam at a depth of 672 feet. These outbursts at the 672 feet level are far less important, as regards volume of gas liberated, than those encountered at 984 feet.

Bore-holes are valueless for draining a seam; and, if used for this special purpose, they give an absolutely false security.

The two essential conditions to be realized in the case of workings characterized by instantaneous disengagement of car-

bonic acid are:—First, the exhaustion of the gas towards the ventilator by an arrangement the sole purpose of which is to ventilate the stalls in which outbursts are feared; second, the absolute prohibition of the pick as a coal-cutter, no advance being made except by shot-firing, which permits the miners to retreat to surface or behind one or more solid, air-tight doors.

Carbonic acid is more capable of causing asphyxiation than fire-damp; and, by reason of its great density, it mixes very slowly with air, and is only withdrawn from workings with extreme difficulty, remaining for a longer or shorter time as a thick cloak upon the floors. Hence the necessity of extremely active ventilation, susceptible of large increase in moments of danger. The deadly nature of the gas has led to investigations for the purpose of determining whether an illuminant capable of burning in irrespirable atmosphere is practically possible.

A. H. C.

The Auriferous Deposits of the Puna de Jujuy (Argentina).

By V. NOVARESA, Mining Engineer.

(Anales de la Sociedad científica argentina, Buenos Ayres, 1893, p. 89.)

The very mountainous province of Jujuy, at the foot of the Andes, is the most northerly of the fourteen provinces of the Argentine Republic, with Chili as its western and Bolivia its northern boundary, Jujuy the capital, being situated 23° south of the Equator (Tropic of Capricorn) 4,100 feet above sea-level, and at about 1,000 miles from the Atlantic coast. Successive ranges of high mountains, running north and south parallel to the Andes, divide the province into a series of valleys, the most important of which is the Quebrada de Humahuaca, through which flows the Rio Grande de Jujuy. Numerous well-watered valleys with tropical vegetation lie east of this river, but west of it the country is quite different, consisting of mountains and extensive plains devoid of vegetation, rising from 11,500 to 13,000 feet above sea-level; and it is this part which goes by the name of the Puna de Jujuy.

The geological features of the Puna have been as yet only superficially studied, but the Author has visited and carefully examined a broad belt of it through which run the main road leading into Bolivia and also some collateral roads leading to the chief towns of the four departments of which the Puna consists. He found it to contain three separate ranges of mountains composed of combined graywacke and schist, often covered superficially by a deposit of oxide of iron, devoid, so far as he could ascertain, of fossils, but containing an abundance of bright pyrites crystals (brasses) in cubes of all sizes, and presumably, like a great part of the Andes, belonging to the Silurian system of rocks. The formation is several thousand metres in thickness and of great

importance, as it contains many auriferous veins; while lying to the east of it, bordering on the Quebrada de Humahuaca, extraordinary masses of conglomerate rock are the characteristic geological feature. The dip of the strata, sometimes towards the west, and at other times towards the east, shows that the rocks have been subjected to much upheaval, and at numerous points volcanic eruptions have thrown up large masses of basaltic rock which assume curious shapes. At one point near Sierra de Covadonga, there is a very extensive region, formed by volcanic action, where flood-waters have subsequently cut deep into the basalt, leaving perpendicular walls from 500 to 650 feet in height, with giant prismatic columns of basalt in the upper portion which are very remarkable.

These eruptions appear to have occurred during the tertiary period, although some of the lavas lie also beneath tertiary deposits. The conglomerates belong to the quaternary period.

The auriferous deposits are found in the most westerly part of the province, and chiefly in the Sierra de Covadonga, which, running south to north for a distance of 75 miles, enters Bolivia near Estorca. The highest point of this range is 17,390 feet above the sea, gold being worked at the mine of La Union 17,060 feet above sea-level. Gold is found in lodes, in the conglomerates, and in alluvial gravels. The auriferous quartz lodes are met with exclusively in the graywacke and schist, more abundantly in the latter than in the former, and, owing to the absence of vegetation, are easily distinguished on the surface, from which their superior density causes them to protrude, at times running parallel to each other and occasionally uniting to form large masses. Their great extent is unquestionable, for the width of the Covadonga mountain cannot be less than 8 or 9 miles, and the quartz lodes are visible throughout the whole length (75 miles), as well as on both slopes and on many spurs of the main range. A notable feature of these lodes is that more gold is frequently found in the surrounding matrix than in the quartz itself.

The population is scanty and mostly Indian, and, although the old workings—galleries, shafts, canals, large heaps of washed ore, ruins of houses, &c.—offer abundant evidence that at some remote period much gold must have been extracted, there does not now remain a single mine properly worked, so that it is impossible to determine the average production of any of the lodes with any accuracy; but, since the completion of the railway to Jujuy, these deposits have once more attracted attention, and recently an Argentine company has opened the mines of La Eureka and La Perdida at an elevation of 14,000 feet, while some Italian residents of Buenos Ayres have commenced operations, and a company has also been formed in Belgium for a similar purpose.

The Author submitted samples taken from the mines of La Perdida and La Cruz del Sud for analysis by the Mint at Buenos Ayres, with the result that some pieces of quartz were found to contain 0.360 oz., 0.536 oz., and 6.430 ozs. per ton, and the slate

matrix 0.180 oz., 2.320 ozs., and 4.016 ozs. per ton; but such tests can have no value for determining the average richness of the lodes. Some argentiferous galena from the La Cruz del Sud mine, which was much mixed with quartz, contained 21.73 per cent. of lead and 8 ozs. of silver to the ton.

The beds of conglomerate are sometimes more than 400 feet thick, but are by no means equally rich throughout. One portion of this rock at the Eureka mine, which is largely composed of pieces of quartz, averages $\frac{1}{4}$ oz. of gold to the cubic metre.

The alluvial gravels on both sides of the Sierra de Covadonga are important owing to their great extent and to the uniformity with which they contain more or less gold. The Author distinguishes them as shallow placers and deep leads, and attributes them to the decomposition of the conglomerates, which again owe their origin to the graywacke, the schist, and the quartz. Those which are richest in gold contain a great deal of fine black sand with a metallic lustre which is magnetic iron ore, and they also abound in cubical pyrites. It is locally believed that gold is most abundant where these brasses are most numerous, and the Author attributes this to the circumstance that both are heavier than the mineral components of the gravel, so that they tend to accumulate together.

O. C. D. R.

A Study of the Daniell Cell. By G. ROUX.

(L'Industrie Électrique, 1893, p. 205.)

The Author, having referred to the thorough investigations already made of this cell, states that his object was to try it under conditions more easy to obtain in practice. He first tried the effect of varying degrees of concentration of the zinc and copper sulphate solutions. A carefully prepared solution, saturated at 16° Centigrade, was diluted with various known proportions of water. The zinc was of chemically pure wire, and the copper had a substantial deposit of pure metal on its surface. It was left in the depositing bath for some hours in order to avoid the subsequent slow increase of electromotive force found to arise when it is removed at once. Measurements were made by means of a potentiometer and a Baille-Féry cell checked by a Clark standard. The former cell is of chloride of lead and chloride of zinc, and has an electromotive force of 0.499 volt. Two forms of Daniell cell were used; the first was of the Fleming U-shaped type, the zinc wire being replaced by a plate about 10 square centimetres (1.55 square inch) in area; the other was cylindrical in shape, a zinc cylinder, 50 square centimetres (7.72 square inches) in area, surrounding a glass tube, open at both ends but contracted at the bottom, containing the copper and copper sulphate solution. Most of the experiments were made with this latter type of cell. A table of

the results is given, and curves are plotted, showing the variation of electromotive force for differing densities of zinc sulphate of known degree of saturation with a solution of copper sulphate of given density. It is shown that, so long as the solution does not exceed $\frac{1}{2}$ saturation, the electromotive force is a linear function of the density; but for greater degrees of saturation the electromotive force diminishes very rapidly, and determinations of it are exceedingly difficult, since the smallest change in the temperature materially alters the density. Below $\frac{3}{4}$ saturation, it is found difficult to get several measurements to agree with one another, and the Author attributes this to a thin layer of zinc sulphate round the zinc which gradually becomes diluted.

The second part of the investigation had reference to the specific resistance of solutions of zinc and copper sulphate, and the way in which it was affected by density and temperature. The solution was contained in a carefully calibrated glass tube, 1 metre (3·28 feet) long, terminating in two large flasks. This apparatus was placed in a lead-lined wooden box in which ice or hot water could be put. The Fousserreau method of test was used; it consists in adjusting a resistance in series with the liquid, and a battery until the difference of potential at the ends of the resistance and of the tube are the same, this equality being determined by means of a Lippmann capillary electromotor in series with a condenser. The electromotor is connected to two wires of copper or zinc at the ends of the tube, and the current is led in by strips of the same metal placed in the flasks. Curves are given showing the variation of the specific resistance with density and with temperature for both sulphate of zinc and sulphate of copper. The former is found to have a minimum specific resistance for a density of about 1·25.

C. H. W.

Apparatus for Measuring Insulation. By H. ARMAGNAT.

(L'Industrie Électrique, 1893, p. 230.)

In 1881 Mr. Carpentier devised an instrument consisting of two concentric coils fixed with their planes at right angles to one another, and embracing a movable system of magnets or soft iron. The coils were connected in parallel, and, on passing current through them, the resultant field caused the movable system to take up a position proportional to the ratio of the currents in the coils, and therefore of their resistances. The idea was not novel, having been published by Maxwell, and Mr. Carpentier abandoned it. With the development of electric lighting a demand has arisen for an instrument that will bear rough usage, and indicate resistances in a simple manner with a fair amount of accuracy. The instrument just described is very suitable, and has been revived by the inventor.

In its original form it was very liable to be affected by the

earth's field, and, in order to render this negligible, the field due to the coils must be very strong. In the improved instrument there is combined the principle of the Deprez-d'Arsonval galvanometer; instead of fixed concentric coils, two rectangular frames are mounted at right angles to one another, and are carried on pivots working in jewelled holes; they move in a very intense field set up by horse-shoe magnets, the circuit of which is completed by pole-pieces and fixed soft-iron cylinders. The current is led into the coils by long spirals of very thin silver wire, the disturbing effect of which on the deflection is negligible at a pressure 20 per cent. less than that employed. One coil is connected to the source of current and the other in series with the resistance to be measured, the circuit so formed being placed as a shunt to the first coil. The resultant field is a minimum when one coil acts alone, i.e., when the resistance to be measured is infinite, and a maximum when the maximum current flows through both, i.e., when the resistance is zero. The disturbing effect of the leading-in wires is, of course, of greatest relative importance when the field is at a minimum, and it is arranged, therefore, that they shall tend to direct the index towards infinity. A switch is provided which alters the sensibility by shunting the coils, the instrument reading up to 50,000 ohms, 500,000 ohms, or 5 megohms, according to the position of the switch. A magneto-electric generator, giving 120 volts at 100 revolutions of the handle per minute, is provided. The Author points out the necessity for the current being continuous in order to avoid error when measuring the insulation of cables having appreciable capacity. When the speed is such that 100 volts is attained, variations in speed do not affect the indications of the instrument.

C. H. W.

An Improved Method of Soldering the Electrodes of Storage Cells.

By K. STRECKER and TH. KARRASS.

(*Elektrotechnische Zeitschrift*, 1893, p. 344.)

In view of the increasing use of storage batteries for telegraphic purposes, the Authors found it desirable to devise means of joining up the lead plates more perfectly than by the soldering-iron, which frequently effects merely a superficial union, and more easily than with the gas blowpipe, which is not very portable, and requires practice to use it. They have worked out the following method. The strips of lead for making the joints are immersed for some time in strong potash solution and then well washed with water to clean the surface. Immediately before the operation the ends of the electrodes and the lead strips are carefully scraped bright; they are then held in position in a mould somewhat in the form of a pair of tongs, which completely encloses

the proposed junction beneath and at the sides; melted lead is then poured in from a ladle till the mould is full. After a little practice it is easy to get the right temperature to ensure the superficial melting of the two surfaces by the hot metal, so as to make a perfect joint.

G. J. B.

On the Evolution of Gas during the Charging of Accumulators.

By C. BRUEGEMANN.

(*Elektrotechnische Zeitschrift*, 1893, p. 341.)

The Author gives the results of about twenty experiments, in which the conditions governing the evolution of gas during the charging of accumulators were investigated. The cells used consisted of a positive plate 8·5 centimetres long, by 7·5 centimetres wide, suspended between two similar negative plates, at a distance of 8 millimetres from it. The positive plate was coated on both sides with the active material, but the negative plates were coated only on the inner sides, so that the efficient area of both kathode and anode was practically the same, viz., 127·5 square centimetres. They were contained in glass vessels of about half a litre capacity.

In order to collect the gases, each cell was closed with a cover of solid paraffin, through which passed two glass tubes. One, dipping into the acid, served for filling the cell, and enabled the density of the liquid to be measured from time to time; the other, opening into a funnel-shaped cavity in the cover, afforded a means of collecting the gas. The strength and electromotive force of the current were measured by two Siemens torsion-galvanometers, and at the commencement of an experiment the cell was completely filled with liquid. At suitable intervals, samples of the gas were collected for analysis. Two characteristic experiments are given in detail. Cell No. 1 was in good working order, but in No. 2 there was local action.

—	Charge.				Total Gas evolved in cubic centimetres.	Discharge.			
	Current-strength in amperes.	Mean electro-motive force in volts.	Am-pere-hours.	Watt-hours.		Current-strength in amperes.	Mean electro-motive force in volts.	Am-pere-hours.	Watt-hours.
No. 1	0·5	2·20	3·75	8·25	216·0	0·5	1·89	3·67	6·92
2	0·5	2·25	5·50	12·38	1,272·0	0·5	1·95	3·25	6·34

The experiment was made under the most favourable conditions for No. 2, the discharge being commenced directly the charging was completed, and yet the efficiency in ampere-hours was 38·8 per cent. less than that of No. 1, and in watt-hours 32·7 per cent. less.

The electromotive force of No. 1 remained almost constant during the first two-thirds of the charging. It then rose, gradually at first, and afterwards rapidly, to a maximum of 2·71 volts. But in the case of No. 2, in which there was local action, the electromotive force rose steadily from the first, the rate only slightly increasing at about the same period of the charging when the rapid rise took place in No. 1. But the maximum attained in twenty hours was only 2·4 volts. There was a marked difference in the rate at which gas was given off, and also in its composition. With No. 1, oxygen appeared first, five and a half hours after the current was turned on, and forty minutes later hydrogen began to be evolved in rapidly increasing quantity, the proportion 2 to 1 being reached after about an hour, at which time the electromotive force was nearly at a maximum.

With No. 2, hydrogen was given off to a considerable extent from the very first, the oxygen only appearing after four hours and forty minutes. At about the eighth hour oxygen was being evolved in the proportion of 14 to 16 of hydrogen. After this it decreased in amount, and at the eleventh hour the proportions were nearly normal. The Author considers that the charging should be stopped when the electromotive force begins to rise rapidly, in order to avoid the loss of energy, corresponding to the evolution of gas which then takes place. Within certain limits the strength of the charging current does not appear to affect the results. The same total volume of gas, having the same average composition, was given off when currents varying from 0·3 to 0·8 ampere were employed. Experiments were made as to the waste of energy from local action in a charged accumulator. During the first four hours 7 cubic centimetres of hydrogen were given off per hour, but by the eighth day the amount had fallen to 1·3 cubic centimetre. It would appear, therefore, that the rate of loss is not constant, as had been supposed. The Author points out the great importance of using pure acid and perfectly clean water for filling the cells.

G. J. B.

The Hummel-Schuckert Meter. By E. MEYLAN.

(L'Électricien, vol. vi. 1893, p. 325.)

This is a motor-meter, and closely resembles that invented by Prof. Elihu Thomson. The main current traverses a thick-wire winding forming the field, while a shunt-current is taken by means of brushes through an armature without iron, in series with which is placed a coil wound so as to assist the main coils, and a fine wire electro-magnet, in the field of which is placed a

copper ring, rigidly attached to the armature, and revolving with it. Neglecting the shunt-winding on the fields, which is intended to compensate for the friction of the brushes, the driving-couple is proportional to the watts, while the retarding-couple is proportional to the speed and to the square of the field in which the disk moves; this last should be constant, and hence the magnet must be saturated.

The meter is double-sealing, and is arranged to be fixed on a wall. The armature spindle is vertical, and the bottom end runs on a jewel mounted on a spring, while the top is merely in a guide. The commutator and brushes are of silver, the latter comprising two pairs of flattened wires bearing edgewise on the commutator, and carried by two forked stems of brass. The Author has found the resistance of these contacts to be very variable. The armature drives the train by means of a worm. The meter is adjusted to read direct by varying the position of an armature placed in front of the poles of the electro-magnet.

The Author tested one of these meters intended for 10 amperes and 110 volts. The resistance of the armature was 229 ohms, and of the electro-magnet and compensating-coil 934 ohms, 1,163 ohms in all; the power wasted in the shunt circuit is therefore 10·4 watts at 110 volts. The main coil had a resistance of 0·09 ohm, and thus caused a drop of 0·9 volt at full load.

The following tests were made:—

(i.) Constant pressure of 98·5 volts:—

Current.	Time of one revolution.	Revolutions per Board of Trade unit.	Current.	Time of one revolution.	Revolutions per Board of Trade unit.
Amperes.	Seconds.		Amperes.	Seconds.	
0·2	47·0	3,888	5·0	2·25	3,249
0·4	25·6	3,569	6·1	1·86	3,221
0·8	13·2	3,461	7·3	1·55	3,230
1·0	10·75	3,400	8·15	1·39	3,226
2·0	5·50	3,322	4·04	2·78	3,255
4·0	2·78	3,287	2·04	5·40	3,318

(ii.) Constant pressure of 100 volts:—

Current.	Time of one revolution.	Revolutions per Board of Trade unit.	Current.	Time of one revolution.	Revolutions per Board of Trade unit.
Amperes.	Seconds.		Amperes.	Seconds.	
0·4	26·0	3,460	8·0	1·39	3,237
2·04	5·45	3,238	10·0	1·14	3,158
4·06	2·74	3,236	13·6	0·825	3,208
6·0	1·88	3,191			

(iii.) Constant current of 2 amperes :—

Pressure.	Time of one revolution.	Revolutions per Board of Trade unit.	Pressure.	Time of one revolution.	Revolutions per Board of Trade unit.
Volts.	Seconds.		Volts.	Seconds.	
111	5·39	3,009	100·5	5·31	3,373
109	5·42	3,047	98·0	5·34	3,440
107	5·35	3,144	95·0	5·48	3,457
103	5·33	3,279			

The meter tested was over-compensated, and when tapped, started without any current in the main coil. The retarding-magnet not being saturated, the instrument registered less for a given current when the volts were high. The Author points out that better results would be attained by increasing the winding on the magnet, but in his opinion it would be still better to substitute permanent magnets, more especially as the meter would then be adapted to alternating currents.

The Author measured the torque of the armature by driving it at a known speed, and measuring the electromotive force produced in it when a known current was passed through the main coils. The maximum back-electromotive force was 0·054 volt, corresponding to a torque of 10·4 gram-centimetres at 10 amperes. The maximum torque in a 15-ampere Thomson meter was found to be 20 gram-centimetres.

The Author found the intensity of the field produced by the main coils when 10 amperes flowed through them to be 120 C. G. S. units.

C. H. W.

The Martin Check-Apparatus for Electric Supply.

(L'Industrie Électrique, 1893, p. 309. 4 Figs.)

It is very usual, in France, for an electric-lighting company to furnish current by contract to consumers, and in such cases a consumer may have any number of lamps installed, so long as he never has more than a certain fixed number lighted at once.

It is therefore necessary to use some apparatus for the purpose of preventing fraud and making it impossible to use more than the stipulated number of lamps at one time. As a rule, this object is accomplished by using switches with two or more different contacts, so that when the current is shut off from one circuit it is admitted to others. This method, however, complicates the internal wiring, and the grouping of the lamps easily permits of fraud. On the other hand, the reliability of cut-outs is very doubtful. The Martin apparatus is designed to prevent the use of

more than the stipulated number of lamps, while permitting absolute freedom in the grouping or wiring of such lamps. Such an apparatus is also of use in a private installation, to prevent overloading of the generating plant. The apparatus is placed in one of the main leads, and consists of two mercury cups provided with a metal contact-maker attached to the end of a lever, and provided with a spring to cause a quick break in the mercury cups. The lever is commanded by one or other of six pins standing at right angles to the flat face of a wheel, which is stationary when the stipulated current is not exceeded, and holds the contact in the mercury cups. Clock-work is so arranged as to always tend to rotate the pin-wheel, and if this motion were not controlled, the circuit would be made and broken at short intervals by the contact-piece in the mercury cups. One of the train of wheels is, however, provided with a single pin, which is held by a projection on a spring lever, during the whole time that the current in the circuit does not exceed the quantity stipulated. The spring lever carries at its free end the armature of an electro-magnet which is placed in the main circuit, and the strength of the spring upon the lever is so adjusted that, so soon as the maximum stipulated current is exceeded, the armature is attracted and the train of wheels set free. Contact is then made and broken at short intervals of time, and the customer is obliged to take one or more lamps off the circuit, thus bringing the current down to the normal, when the train of wheels is stopped and permanent contact is again made. In actual practice, a clock movement of the Japy type is employed, but only the five wheels of the striking mechanism are preserved, with the detent-spindle and its lever, and the spindle of the hammer. The hammer-shaft is retained, but the head is replaced by a piece of hard rubber, carrying a copper fork dipping into the two mercury cups. The Author gives some further details of the method of manufacturing this particular type of clock. He states that the act of switching in a 5-candle-power lamp on a circuit of 110 volts is sufficient to actuate the apparatus, supposing, of course, that such a lamp be in excess of the stipulated number of lamps which are already lighted. The loss of pressure upon the circuit is said never to exceed 0.2 volt. The whole is covered with a glazed lid, and can be sealed up. A counterpoise is so arranged that it is impossible for a consumer to keep too many lamps lighted until the clock has run down, in which case the circuit would become permanently closed; the counterweight causes the circuit to remain permanently open until the number of lamps in use is reduced to the stipulated maximum.

This instrument has, it is stated, given satisfaction in one of the eastern towns, and a servant of the company calls once a month upon each customer for the purpose of winding up the apparatus. Such a clock-movement would run for 15 days, and give 2,700 interruptions, and it is found that the spring is very seldom run down in a month.

E. R. D.

*On the Estimation of Electrical Resistance by means of
Alternating Currents.* By F. KOHLRAUSCH.

(*Annalen der Physik und Chemie*, vol. xlix. 1893, p. 225.)

The Author has investigated the conditions and limits of accuracy in the measurement of resistances by his telephonic method. The apparatus is similar in principle to the metre-bridge, but the wire is three times the usual length, and has a resistance of 10 ohms. Two extra coils of 45 ohms can be inserted symmetrically, or both on one side of the bridge. The telephone is in connection with the two ends of the wire, and, in place of the usual battery, the secondary of an induction-coil is in circuit with the rider and the middle terminal of the bridge. The coil generally used by the Author has a solid iron core. The resistance of the primary is 5 ohms, and that of the secondary 30 ohms. It is driven by an accumulator, the interruptor being a platinum point dipping into mercury under distilled water, and making about eighty-five vibrations per minute.¹ The platinum point is in connection with the negative pole. In measuring a resistance the rider is adjusted until the sound of the induction-coil is no longer audible in the telephone.

The Author arrives at the following conclusions. Under favourable circumstances the error by this method is less than 1 part in 10,000. If the position of minimum sound is indefinite by reason of polarization, or of the self-induction or the capacity of the apparatus, then the middle point between two positions of equal intensity of sound gives the relation of the resistances with tolerable accuracy. The construction of the coils is a matter of some importance. Up to about 1,000 ohms, the ordinary bifilar winding gives good results, but at 4,000 ohms the error may be about $\frac{1}{3}$ per cent., and the position of minimum sound is ill-defined. This error increases, according to Wien, with the square of the capacity and of the resistance. Coils made after the method of Chaperon, in which the successive layers are wound in opposite directions, are free from this defect, and may be used up to 30,000 ohms. It is better to use several small coils instead of a single large one in making up a rheostat of high resistance, on account of the greater capacity of the apparatus in the latter case. Thus five coils of 1,000 ohms in series gave a well-defined minimum, whereas with a single coil of 5,000 ohms the telephonic method was almost worthless. By the use of an adjustable condenser suitably arranged, the disturbing effect of the capacity of the coils may be in a great measure eliminated.

The error due to polarization decreases as the resistance and the surface of the electrodes is increased. With polished electrodes, when the product of the area in square centimetres by the resist-

¹ Elsewhere the rate is spoken of as 60 to 140 vibrations per second.—Ed.

ance in ohms amounts to 250 or more, the probable error from polarization does not exceed 1 per cent. But the Author recommends that polished electrodes should only be used for special purposes. They should be thickly platinized until a matt surface is obtained. Such electrodes, of from 10 to 35 square centimetres area, used with resistances of from 50 to 8 ohms, may be considered free from polarization, the error being under 0.1 per cent. In dealing with very high resistances it is necessary to keep the induction-coil at a distance from the measuring apparatus, and to place both telephone and bridge in such a direction with regard to the lines of force that their disturbing effect may not appear. In measuring the resistance of a fluid, the influence of the electrostatic capacity of the containing vessel may be felt, and the same effect may be observed when the resistance is immersed in a water-bath. In both cases the difficulty may be got over by the use of an adjustable condenser. A bath of petroleum was free from this objection. If the resistance to be measured is considerable, e.g., 100,000 ohms, disturbing noises, due to static charges, are heard in the telephone. These may frequently be sufficiently reduced by connecting some point on the circuit with the earth. In such cases the telephone may show signs of being unsymmetrical, that is to say, on reversing its connection with the bridge, or changing the direction of the induced currents, the position of minimum sound may alter, even as much as 4 per cent. This error is to be eliminated by reversing the telephone, and taking the mean of the readings. It is probably due to static charges, and was most marked when using an induction-coil with a core consisting of a bundle of wires.

G. J. B.

The Champs-Élysées Electrical District, Paris. By E. HOSPITALIER.

(*L'Industrie Électrique*, 1893, pp. 149, 161.)

Paris was backward in electric lighting, the first station being opened June 20, 1887, with a maximum capacity of only 1,500 lamps, the charge being 1s. 7½d. per Board of Trade unit. Progress has been rapid, however, since the end of 1888 when the municipal council drew up specifications and granted concessions, the town being divided into five sections. The largest is that of the Champs Élysées, and covers 2,718 acres; a map is given showing the portion of the town included. The district is a scattered residential one, and the demand extremely variable. The work was begun in April, 1892, and officially opened in March, 1893, the engineer being Mr. George Ebel. The system adopted is a high-pressure alternating one (3,000 volts), with transformers in the consumers' houses; the station is situated outside Paris, and is nearly 5 miles from the furthest point. The

periodicity is 40, the object of keeping it low being to facilitate parallel running and the use of motors, and to keep down the transformer losses on low loads.

The station is on the banks of the Seine, sufficiently far away from Paris to cause no nuisance by smoke, noise or vibration.

Buildings.—Those actually erected cover an area of 2,990 square yards, but space is reserved for extension; a plan and section are given, and the construction described.

Steam-Production.—The water for the boilers and condensers is drawn from the Seine by centrifugal pumps, and is purified before use. The boilers are of the Galloway type, and were made at Rouen; they are five in number, and full particulars of them are given. The chimney is 10 feet 6 inches internal diameter at the base and 131 feet high. The products of combustion either pass into the chimney direct or through a Green's economiser of 384 tubes; in the former case the guaranteed evaporation is 8.42 lbs., and in the latter 9 lbs. of steam per pound of coal, the pressure being 85 lbs. per square inch.

Engines.—These are by Farcot, of Saint-Ouen, are condensing, and run at sixty revolutions per minute; they comprise two Corliss engines, cylinders 25.6 inches diameter and 4.26 feet stroke, cranks connected at right angles to one another, and driving a 400-kilowatt alternator and 25-kilowatt exciter; also two Corliss engines, cylinders 32.6 inches diameter and 4.59 feet stroke, each driving independently a 400-kilowatt alternator and 25-kilowatt exciter. A Table is given showing the guaranteed steam-consumption at different loads.

Alternators.—These are by Messrs. Hillairet and Huguet, of Paris, and are at present three in number. The armature is stationary, and the field-magnets revolve; they are 19 feet in diameter, have eighty poles, and are keyed on the engine shaft. The fixed armature has eighty bobbins, and gives 133 amperes at 3,000 volts, with a periodicity of 40 per second. The output can be increased to 455 kilowatts in case of emergency, and the guaranteed commercial efficiency is 85.5 per cent. Particulars are given of the distribution of the losses, and of the guaranteed steam-consumption per unit.

Switchboard.—All the circuits and connections are well in sight, and the live portions are painted bright red. The whole board, 65.6 feet long and 13.1 feet high, is insulated from earth on porcelain insulators. Switching on and off of the high-pressure circuits is effected by joining fixed terminals by means of mercury contained in ebonite cups manipulated by levers, the position of which indicates very clearly whether a switch is on or off. Three longitudinal pairs of bars are provided, one connected to the exciters, the second to the mains, and the third to the artificial load resistances. Each of the three 25-kilowatt exciters is connected through a double pole switch to the exciter bars; the machines are shunt-wound, and the magnets are fed off these bars, each having its own adjustable resistance. In addition, a resist-

ance, common to all three, is provided, and admits of altering the excitation of the three at once. The magnets of the alternators are connected each through a resistance, an ammeter and a switch to the exciter bars; the output of each alternator when running in parallel can thus be regulated. The distributing bars can be connected to any alternator, any feeder and any one of the three phase-indicators. The artificial-load bars can be connected to any alternator, any phase-indicator, and to the "day-service feeder" (see below.) The artificial load is divided into two equal parts connected in parallel on the bars; each has twenty contacts, each of which connects a resistance absorbing 10 kilowatts at 3,000 volts. In parallel running the machine to be put in is run up to speed, and is then gradually given an artificial load by steps of 10 kilowatts; when fully loaded it is switched in with the one running the load and the artificial load is then gradually removed. To take a machine out the process is reversed. This method avoids abrupt changes in pressure, and is found simple, certain and comparatively quick. The phase-indicators consist of two transformers having their primaries joined to the distributing and artificial-load bars respectively, and their secondaries in series with one another and with two lamps. All the feeders are connected in parallel to the distributing bars, each through a double-pole switch. One, the "day-service feeder," has two double-pole switches, enabling it to be put on the distributing or on the artificial-load bars respectively in order to admit of repairs, &c., being executed.

Mains.—There are underground concentric Berthoud-Borel armoured cables; the ultimate number is eleven, but only one is yet laid. All will run to one point a little over two miles from the station. Each has an area of 200 square millimetres (0·31 square inch), and will work normally at 0·8 ampere per square millimetre giving a loss of 3 per cent.; at times the density will be 1 ampere per square millimetre with a loss of 3½ per cent. Except the cables for the Champs Elysées, which are of the same size as the feeders, all those from the main feeding-point will be 150 square millimetres (0·23 square inch) area. Tables showing the thicknesses of the several materials, the weight, insulation, capacity, and resistance of the cables are given. Under footpaths the cables are laid in sand in a trench, earthenware plates and wire netting being placed over them. Under roads they are drawn into cast-iron pipes. Cast-iron junction boxes filled in with pitch are used for straight and tee joints, and for connecting separate cables from switchboard or transformers. Fuses are placed at the extremities of the feeders and at changes in section; they are contained in ebonite cylinders provided with metal ends which slip in between spring contacts connected to the cables. The whole is placed in a cast-iron box with rubber-packed lid filled up to the spring contacts with insulating material, the remaining space being dried with chloride of calcium. This box is placed in a brick chamber with cast-iron lid.

Consumer's apparatus.—Ganz transformers and Thomson meters are used ; particulars of the efficiency of the former are given.

The article concludes with the text of the regulations imposed on the consumer, scale of charges, &c.

C. H. W.

The St. George Sub-station in the Edison Electrical District, Paris. By G. Roux.

(*L'Industrie Électrique*, 1893, p. 231.)

This is a battery station established to maintain constant pressure at an outlying portion of the district by supplementing the feeders, this being found cheaper than augmenting the size of the latter. The battery being always connected to the constant-pressure mains, and steam-engines being inadmissible, the following method was adopted to charge it:—A sufficient number of cells were withdrawn to enable the remainder to be charged at the ordinary pressure, those withdrawn being charged from a continuous current transformer run off the mains.

The three-wire system is used, fed at 220 volts, and the battery is accordingly divided into two halves. Switches are provided that admit of the number of cells being varied, so that the battery is either being charged or is discharging into the network, thus allowing the balance of the two sides to be adjusted. Other switches permit any desired number of these regulating cells to be charged by the transformer. This is composed of two separate machines, connected by a Raffard coupling; the motor is run off one side of the system and drives a dynamo giving 350 amperes at 90 volts. The circuit is automatically broken in case of accident.

The battery comprises one hundred and twenty-eight Tudor T.U.16 cells, each having seven positive and eight negative plates built up of sixteen separate plates 5·51 inches high, 5·32 inches wide, and 0·53 inch thick, sweated together by means of two lugs at opposite corners of a lead frame in such a manner as to admit of free expansion. The plates are mounted parallel to one another in a lead-lined box, and rest on glass plates standing on edge vertically beneath them. This arrangement allows the oxides applied to give an initial charge to the battery to fall freely to the bottom. The plates are guided by means of grooved glass, and are kept at equal distances by glass tubes slightly embedded in them. The ends of the plates are burnt on to a lead bar, thus ensuring a low resistance for the connections. Each cell rests on four glass insulators, each of which is in two parts, the lower being filled with a heavy oil and covered with the other, a piece of lead being placed between the two parts in order to equalize the weight.

The following particulars are given:—

Charging current.		420 amperes.
Discharge current	{ for ten hours	280 "
	" five "	476 "
	" three "	672 "
Useful capacity	{ when discharged in ten hours .	2,800 ampere-hours.
	" " five "	2,380 "
	" " three "	2,016 "
Weight of plates		1,021 lbs.
Total weight without acid		1,428 "
Quantity of acidulated water		39½ gallons.

Of the one hundred and twenty-eight cells, forty-two are connected to the switches, being joined thereto by copper bars.

The energy of the charge and discharge is measured by Thomson meters furnished with two dials; the armature turns in opposite directions for charge and discharge, and engages with one or other train of counting wheels.

The battery is guaranteed for ten years, and its maintenance undertaken for an annual sum not to exceed 3½ per cent. of its cost.

C. H. W.

Small Arc-Lamps and Gas Glow-Lights. By C. HERR.

(*Elektrotechnische Zeitschrift*, 1893, p. 196.)

The improvements made in gas glow-lights during the last year have induced electrical engineers to attempt the construction of very small arc-lamps which should be capable of competing against them. Although hitherto arc-lamps for 4 or 6 amperes had been made, their use in small shops or show windows is not economical, and for such purposes arc-lights requiring only 1·5 or 2 amperes are preferable. Various firms are now making such lamps, and the Author gives the results of tests for economy which he has made on two lamps, one requiring 1·5 and the other 2 amperes. The upper carbon is 8 millimetres and the lower 5 millimetres in diameter, the length of carbons allowing the lamps to burn for five hours. Photometric tests were made under various angles, ranging from the horizontal to the vertical, and the Author finds that with 1·5 ampere and 33 volts at the terminals of the lamp, 118 candle-power is obtained at an angle of 37½° from the horizontal. He gives the diagram of the distribution of light, which shows a rapid falling off in candle-power on either side of the maximum.

By reducing the surface of the diagram to an equivalent quadrant, he finds that 1 spherical candle-power is produced by an expenditure of 0·86 watt. The uneven distribution of light is mostly due to the short arc, and to improve this the Author has also worked the lamp at 37 volts; but the photometric measure-

2 H 2

ments showed that the efficiency was thereby reduced, the consumption being 0.905 watt per spherical candle-power. One expedient for increasing the facility for the escape of light from the arc was to use thinner carbons, but in this case the efficiency was found to be still lower—the spherical candle requiring 1.04 watt. Similar tests, and with similar results, were made with the arc-lamp for 2 amperes. The Author recommends that such lamps should be burnt at a pressure not exceeding 33 volts, so that, where two lamps are placed in series on 100-volt circuits, a certain amount of resistance must be inserted. To avoid waste in this resistance, the Author recommends the use for it of two 16 candle-power glow-lamps in parallel, which can be fixed in any convenient position for lighting.

Two of the improved incandescent gas-burners were also tested photometrically, and the results plotted in the manner previously adopted for the arc-lights. The mean result between the two sets of tests is 0.315 cubic foot of gas per spherical candle-hour.

He next proceeds to calculate the total cost of illumination by the two systems, taking the unit of electrical energy at 9d., the cost of carbons per hour at 0.18d., and 0.24d. for the 1.5 and 2-ampere lamp respectively, and the cost of gas as 4s. 5d. per 1,000 cubic feet. He assumes a life of four hundred hours for the refractory mantle of the gas glow-light. The cost of the arc-lamp is taken at £3 5s., and that of the gas glow-lamp at 15s. Allowing 12 per cent. for sinking fund, and assuming the annual lighting time to be eight hundred hours, he finds the following figures for the cost of one hundred candle-hours:—

	d.
Arc-lamp of 1½ ampere	1.75
" " 2 amperes	1.70
Gas glow-light	1.18

In this calculation the Author has not made allowance for the reduction of illuminating power of the gas glow-light with age. If this point is taken into account, its cost comes very nearly to that of the arc-light.

G. K.

The Central Electric-Lighting Station, Fürstenfeld-Bruck.

(*Elektrotechnische Zeitschrift*, 1893, p. 223.)

This central station, although one of the smallest in Germany, is remarkable for the low cost at which the works were carried out. The generating machinery is situated in Schöngesing, about 4½ miles from the town to be lighted, and the motive power consists of two turbines, with provision for a third in future. Detailed plans of the station are given, as also of the generators, transformers and motors used in Fürstenfeld-Bruck. The two generators are ordinary alternators, made by Messrs. Brown,

were installed in consumers' premises. This reduced the consumption of current 30 per cent. In spite of this, however, sufficient power could not be obtained from the fall, and accumulators were judged necessary. Alternating-currents could therefore not be used, and in order to reduce the cost it was decided to use as small a number of accumulator-cells as possible.

A turbine of 60 HP. has been placed at the waterfall, and drives a shunt-wound dynamo, giving 800 volts and 50 amperes, from which current is taken to a motor in the town, and also, if needful, to charge the accumulators. The dynamo is connected to the central station by a line consisting of two copper wires 0.235 inch diameter and 2.16 miles long; the motor is also shunt wound, and requires a current of 50 amperes at 600 volts; it is directly coupled to a dynamo giving 250 amperes at 105 volts. At full load the efficiency of the dynamo is 90 per cent., and that of the line 75 per cent.; the total efficiency is thus 54.6 per cent. The power furnished to the town is therefore $60 \times 54.6 = 32.8$ HP., or 24 kilowatts. A battery of fifty cells is used, and it is therefore necessary to charge or discharge these accumulators while still maintaining a constant difference of potential upon the circuit.

For this purpose a motor is supplied with current from the dynamo giving 105 volts, and the motor is directly coupled to a small dynamo giving 200 amperes at 30 volts, and used either to add 30 volts to the 105 volts upon the circuit to charge the accumulators, or to add 5 to 10 volts to the potential of the cells when discharging, to bring their potential up to 105 volts. This small dynamo has a special winding of its field-magnets, in order to obtain the required result; one winding of fine wire is taken off the 105-volt machine, and has in it a rheostat, by which the exciting current can be regulated; the second winding is supplied by the current in the motor. In this manner an almost automatic regulation of the pressure upon the outside circuit is obtained.

During the day the power obtainable is in excess of that required for consumption, so the small dynamo is used to raise the pressure sufficiently to charge the battery. As the output increases the charging-current diminishes, and at last becomes zero; it is then merely necessary to change the connection of the small dynamo, which then adds to the pressure of the battery the number of volts required to obtain the pressure upon the distributing circuit. When the output falls the connection is again reversed to charge the battery. All the dynamos are of the Thury type, with self-lubricating bearings and carbon brushes.

A steam-engine has been retained in case of accident, but it is reduced to 60 HP. by simply lowering the speed. By this change in the plant the power of the plant has been reduced to one-half, therefore the load-factors have been doubled, and the efficiency of the various machines would be increased if it was found necessary to use steam-power at any time.

E. R. D.

Electric Generating-Station of Bazacle (Toulouse).

By P. JUPPOUT:

(Le Génie Civil, vol. xxiii., 1893, p. 97.)

The Garonne at Toulouse crosses two weirs, the second and more important of which provides the power made use of in the new generating-station here described, which is a central station distributing current both for lighting and for motive power.

The head of water is 14 feet 9 inches, and the hydraulic installation had to be so arranged as not to interfere with the mills already using the water-power of the fall. Four turbines of the Girard type were erected, each being able under the full head to develop 320 HP. The power is under control by means of cast-iron valves sliding across the fourteen orifices on each turbine; these are worked either by hand or from two auxiliary turbines provided for the purpose. The turbine-shaft is vertical and drives by bevel gearing (wood and iron) a horizontal shaft, from which a belt is taken to the dynamo.

The demands for power have so much increased that steam-engines have had to be provided also, which can be coupled at will to the same dynamos. Soapy water is used for lubricating the footsteps of the turbines and gives satisfaction.

The dynamos are six in number, made by Messrs. Guénod and Sautter of Geneva. The current is continuous. At a speed of 380 revolutions each develops a current of 700 amperes at 150 volts. Each turbine, with its two dynamos, will supply twelve thousand lamps. The three-wire system of distribution is used.

In order to maintain a constant electromotive force at the end of the line, the speed of the turbines is regulated to suit the consumption, and the moving masses being large, this method avoids any sudden change, such as might be a danger in directly varying the magnetic field for the purpose of regulation. The entire control of both mechanical and electrical apparatus is concentrated at one point under the eye of the electrician in charge. Eight feeders have been established, all overhead lines, with a development of 13 miles and within a radius of 1,300 yards from the station.

In order to cope with the increased demand, which went very soon beyond the amount of current originally provided for, two accumulator stations have been established and a third is projected. These are charged by isolating one of the feeders from the general system at a time when the demand is slack.

The municipality have adopted the company's current for street lighting, there being now two hundred and eight arc-lamps in use. They are suspended over the centre of the street from a pair of posts in the line of the kerbs.

The motors supplied by the current vary from $\frac{1}{8}$ th HP. to 4 HP., and the price paid is £20 per HP. per annum. 125 HP. in all is supplied.

The total receipts for light and power in 1892 amounted to nearly £24,000.

C. F. F.

Tests of Street-Railway Return-Circuits. By L. T. GIBBS.

(The Electrical World, 1893, p. 425.)

The Author gives the results of tests made during the winter of 1892-93 to ascertain the loss of pressure caused by the resistance of the return circuits in street railways. The method of testing was to simultaneously observe the station voltage, and the available pressure at various parts of the line, for which purpose an existing telephone circuit passing over the poles supporting the trolley-wire was utilized. The track is laid with girder-rails weighing from 58 to 79 lbs. per yard, and connected at each joint with galvanized-iron bands, simply riveted into the web of the rail. At distances of 90 feet cross-bonds are inserted, consisting of $\frac{1}{8}$ -inch galvanized-iron cable. Where the lines cross rivers, the connection between the track on the opposite side of the river is made by stout copper wires sunk in trenches; and to improve the carrying-capacity of the rails generally, supplementary copper wires are run in certain places laid in grooved timber, either between or on the side of the track, the groove being filled with a mixture of pitch and tar, and closed by a cover of 1-inch pine nailed down. The line is worked on the overhead-feeder system, the resistance of the feeders being so chosen as to obtain as nearly as possible a uniform drop all over the track. The tests were made between 5 and 7 P.M., when the total load on the station averaged 2,000 to 2,200 amperes. The drop in pressure was tested in twenty-three points on the system, and the Author gives an elaborate table showing the results obtained. Averaging the whole of these results, it is found that with a station voltage of 455.5 volts, the average drop throughout the system is 52.5 volts. In discussing the permanency of the circuit, the Author thinks that the tie-wires will not have a longer life than two years, and he ascribes this to electrolysis, which not only attacks the tie-wires, but also any pipes which may be in the ground in their neighbourhood, his experience being that lead pipes suffer more than iron pipes. He recommends the use of heavier return-circuits in addition to the rails, as the most efficient means of increasing the economy of working.

G. K.

Heating of Armatures. By A. H. and C. E. TIMMERMAN.

(Transactions of the American Institute of Electrical Engineers, 1893, p. 342.)

The results detailed below were obtained from a model shaped as an armature with a german silver coil for generating the heat by passing through it the necessary current; and with an external copper coil for determining the temperature from its rise in resistance. The following deductions are recorded.

Increase in the temperature of the armature causes increased radiation per degree rise in temperature, but the rate of increase diminishes as the temperature increases, and increase in the amount of heat generated does not proportionately increase the temperature of the armature.

The effect of the surface covered by the field is to reduce the radiation, and the temperature is thereby raised, or at any rate, at higher speeds, and where the rise is not more than 50° Centigrade.

As the peripheral velocity is increased the amount of heat dissipated is increased, but the rate of increase diminishes as the velocity increases.

The highest radiation that can be obtained for a drum armature of ordinary construction is about 0.03 watt per square inch per degree Centigrade rise in temperature, when that rise is not over 100° Centigrade; but in large machines this figure will probably be higher.

F. J.

The Electrical Fountains at the Chicago World's Fair.

(The Electrical World, 1893, p. 354.)

The generating-plant for this work comprises four 175-kilowatt 140-volt Edison bi-polar dynamos, having commutators 14 inches long and 12 inches diameter, with 41 segments. They are coupled up in pairs for three-wire supply, the two pairs being belt-driven by separate engines; one of these is a 600-HP. Ball compound condensing engine, the other a 400-HP. Armington and Sims' high-pressure engine.

Four Worthington pumps are employed, having a daily capacity of 15,000,000, 12,500,000, 7,500,000, and 5,000,000 gallons respectively. Full particulars are given as to the dimensions of cylinders, length of stroke, &c. It is expected that the water will be thrown to a height of from 150 to 175 feet. Details are given of the steam and water-pipes; of the latter, the main delivery is 48 inches diameter; this divides into a 36-inch, supplying the central fountain, and a 24-inch, which again branches into two

16-inch, supplying the two electrical fountains, the jets in each of which are thus summarised :—

Central "geyser"	7
" ring	84
Inner circle of "composites" 6 by 7	42
Central jets (2 each) of outer circle of "composites" (12)	24
"Wheat sheaves" (12 with 116 jets each)	1,392
Total	1,549

The arc-lamps used for illuminating the jets are of the standard Thomson-Houston marine search-light type. The carbons are horizontal, and are gripped in brass tubes, which are themselves held in the holders; they are fed by means of a right- and left-handed screw, the portion feeding the positive carbon having a double thread. The negative holder has a ratchet arrangement which admits of a rough adjustment of the distance between the carbons being made by hand. The positive carriage has three hand-adjustments, allowing movement in three planes at right-angles to one another. The arc is struck by means of a small electro-magnet in series with it. The feeding-mechanism is actuated by a pair of magnets worked by a shunt current, and is described in great detail. Each lamp takes 80 amperes; the positive carbon is 1 inch in diameter and is cored, while the negative is solid and $\frac{3}{4}$ inch in diameter; the (spherical) candle-power is said to be 220,000 candles. The arc is placed in the focus of a silvered copper paraboloidal reflector, 22 inches diameter and 12 inches deep, with a focal length of 2·04 inches. The light is thrown vertically upwards through a cast-iron tube 2 feet in diameter, closed at the top by a thick glass plate, over the centre of which the supply-pipe is bent. The lamps are placed in a chamber beneath the fountains, and nineteen are assigned to each fountain.

For producing coloured light, each lamp is furnished with six glass fan-shaped screens mounted on a vertical spindle; and these spindles are so geared together as to be worked by three hand-wheels controlling the screens of the central jet and the two rings respectively. In front of the operator is placed a box for signalling the colours required. It is divided into three vertical portions, each of which is subdivided into eight portions by horizontal divisions. Each division is fitted with a pane of glass, behind which is placed a glow-lamp. The three top panes are of ground glass, and each bears the number of a hand-wheel; then follow six colours in each vertical row corresponding to those on the screens, and the bottom pane in each row is of ground glass, bearing a black spot, and indicates "no change." A similar box is placed in the signalling-tower, where switches, arranged like the panes, and coloured to correspond, are fixed; these control the lamps behind the windows. A bell gives warning when a change is required.

The signals for the valves are given in a precisely similar manner, and two windows are provided, showing either "pulsate," i.e., move valve quickly backwards and forwards, or "project," i.e., open suddenly. Signals are given between the valve-room and pumps by means of a bell and code of rings. The chambers and signalling-tower are also in telephonic communication.

With the exception of that for the central geyser, all the lamps are controlled in pairs, each pair having a rheostat, a double-pole switch to cut it out and a single-pole switch to connect it to an ammeter fixed on the board which carries all the switches; a voltmeter is also provided. Great care is taken to equalise the drop of pressure so as to maintain nearly perfect balance in the three-wire system.

C. H. W.

Application of Three-phased Currents to the Working of Overhead Travellers.

(L'Industrie Électrique, 1893, p. 259.)

The Author, having referred to other users of these currents, proceeds to describe an overhead traveller made by Messrs. Guitton and Bertolus, of St. Etienne, for the Oerlikon works.

Three motors are provided, one for hoisting, one for traversing, and one for travelling. Each is independent of the others, and can be reversed at will, and all may be at work simultaneously. Current is supplied from three copper conductors run on insulators fixed on one side of the gantry, contact being made by rollers pressing on the under side of the wires. Insulated cables take the current to the switchboard where three levers are fixed, each controlling the starting and reversing of a motor. The motors on the traversing carriage are supplied with current in the same way as the main carriage.

The motors are very simple and strong, and have neither brushes nor commutators, the only wear being at the brasses. The cost of maintenance is merely the expense for oil, which is low on account of the method of lubrication adopted. The machines start easily, and if overloaded merely pull up without being damaged in any way. Two different speeds of hoisting can be attained, and are controlled from the switchboard; a brake, operated either from this board or from the ground is also provided. The endless screws of hardened steel are completely enclosed in an oil bath, and gear into wheels of phosphor bronze. The worm-wheels of the hoist are of cast-steel.

C. H. W.

The Electrical Illumination of Steam Railroad Cars.

(The Electrical World, 1893, p. 363.)

A car on the New Jersey Central Railroad has been fitted with 25 eight candle-power glow-lamps run on the Young Muscowitz system. The dynamo is driven from an axle of one of the bogies through the intervention of two chain-driven countershafts and a belt. Uniform speed is attained by means of two Evans friction-cones, one of which runs the other, the speed being regulated automatically by means of a centrifugal governor on the lower cone which shifts the belt. A device is provided which prevents the apparatus from coming into action until the car attains a speed of 7 miles per hour, after which the dynamo is said to run steadily up to the full speed of the train. Storage-cells are used to feed the lamps when the car speed is below 7 miles per hour, and they are charged by the dynamo when no light is required, and when the car-speed is high. The whole plant weighs about 1,000 lbs., but it is expected that this will be reduced. The car has run nearly 4,000 miles, over a line with many crossings and curves, and has given great satisfaction.

C. H. W.

Compensation for the Effects of Magnetic Hysteresis.

By F. GUILBERT.

(La Lumière Électrique, vol. xlviii. 1893, p. 518.)

The effect of hysteresis in instruments based on electro-magnetic action is to cause a variance in their movement, or indications at any given current, according as the intensity is increasing or diminishing. Mr. Abakanowicz proposes to obviate this by opposing two electro-magnets, in which, though the intensities of the fields are different, the magnitude of the hysteretic effect is balanced by choosing iron of different qualities for each of them. Thus, by proper disposal of the electric and magnetic conditions, it will be possible to render the mechanical motion resulting therefrom unaffected by hysteresis, because the latter will be balanced in the two opposing actions, while the former may be made of any desired magnitude.

The application of the principle enunciated above is illustrated in the cases of a watt-meter, a solenoidal core, and an ordinary electro-magnet attracting an armature, but it is not stated that any actual instruments have yet been constructed.

F. J.

Practical Aspects of Low-Frequency Electrical Resonance.

By M. J. PUPIN.

(Transactions of the American Institute of Electrical Engineers, 1893, p. 369.)

The effect of self-induction and capacity in an electrical circuit acted on by a periodically varying electromotive force, is compared to the analogous conditions of an impressed force applied to a body of a given mass through an elastic medium; and in this way the similarity in results are worked out, especially when the period of the impressed force corresponds with the time-constant of the circuit. The results theoretically deduced are illustrated by actual experiment, and it is from these actual experiments that the effect of hysteresis in the iron core of the self-induction coil and of the dielectric in the condenser are shown to play important parts in modifying previously formed conclusions.

Thus the resonant rise of potential is enormously reduced by the presence of iron, which at the same time tends to wipe out upper harmonics superposed on the fundamental period. It is incidentally shown that the method employed by the Author of gradually attuning, as it were, the electrical circuit to the period of the electromotive force, and observing the change in the value of the latter affords simultaneously a most convenient means of discovering the existence of such higher harmonics. Thus, in one of the experiments on a coil without iron, a triple harmonic was proved to exist, and the rise of electromotive force was about twenty-five times, while with iron the rise was only about one and a half times.

Two peculiar features in the behaviour of iron are specially mentioned; the first that the quantity of iron under certain conditions in the core of a coil had only small influence on the period of resonance; and the second that when resonance is established by insertion of the proper amount of iron in a coil, it is possible to gradually alter the quantity, and still not disturb the resonance; but in this condition the circuit is unstable, so that the mere approach of a very small quantity of iron is sufficient to completely upset the resonance. The same effect can be obtained by slowly altering the capacity; if this be done without sparking, the resonance will persist, but the slightest spark overthrows it immediately.

As a note of practical importance, the Author adds that when a large inertia coil without iron is joined in series with an alternator and a condenser, in all machines he has tried, upper harmonics are absent; but if the primary of a transformer introduced in the circuit then they make their appearance.

F. J.

On Electrical Discharges: the Production of Electrical Oscillations and their Relation to Vacuum-Tubes.

By H. EBERT and E. WIEDEMANN.

(Annalen der Physik und Chemie, vol. xlviii. 1893, p. 549.)

The Authors claim to give a qualitative and quantitative explanation of many of the phenomena of electrical discharges through rarefied gas. They consider every vacuum-tube to be essentially a condenser, of which the electrodes form the coatings and the gas the dielectric. The material of the tube itself acts partly as a coating and partly as a dielectric. The capacity is in general very small, and depends on the form and material of the tube, and the nature and pressure of the gas. For the purposes of the investigation it was necessary to submit the gas to the influence of electrical oscillations of definite period and rate of damping. The source of electricity was a large influence-machine of twenty plates, enclosed in a glass case with strong sulphuric acid to absorb moisture. This was connected with the primaries of an air-condenser the plates of which were from 20 to 30 centimetres (8-12 inches) square, according to the capacity required. The distance of the secondary plates from these could be varied from 2 to 8 centimetres (0.8 to 3.2 inches). In some cases circular plates were used. To the secondary was attached a pair of "Lecher's Wires;" these were of several sizes, from 0.05 centimetre to 1.045 centimetre (0.02 inch to 0.4 inch). Each pair was tried at 10 centimetres (4 inches), and 30 centimetres (12 inches) apart. For studying the position of the nodes, wires of 11-14 metres (35 feet 9 inches to 45 feet 6 inches) were used, but for investigating the effect of a second condenser at the further end of the system, a shorter length of from 4 to 6 metres was preferred. This was especially the case when tubes without electrodes were employed. The variations of potential in the second condenser, when the wires were connected by a bridge at any given point, were measured by an electrometer according to the method devised by Francke.¹

The following are some of the results.

General conditions of the illumination of rarefied gases in an electrical field.—(1) Tubes of different dimensions do not respond with equal ease. They answer best when wide and not too short.

(2) Tubes without electrodes should be coated inside at each end with platinum or silver. The latter is to be avoided, as it

¹ Annalen der Physik und Chemie, 1891, vol. xlv. p. 713.

may be acted on by the mercury vapour. A convenient method is to moisten the parts on which a deposit is required with a solution of platinum chloride in alcohol, to which some oil of lavender has been added, and then apply heat until the liquid is driven off.

(3) Tubes whether with or without electrodes respond more easily (i.e., with a lower difference of potential) for some little time after they have been used.

(4) The nodes indicated by the positions of the bridge corresponding to maximum illumination of the vacuum-tube, are independent of the pressure of the gas. But the range on either side of a node through which the bridge may be shifted without causing the light to disappear, increases rapidly with the degree of exhaustion. Accordingly, in determining the exact position of a node, the pressure used should be the highest at which the discharge will take place.

(5) In dealing with a system of several nodes it is necessary to bridge over those near the end condenser with the greatest accuracy, otherwise the tubes will not respond to the bridging of the rest. It is difficult to work with more than six nodes.

Relation of the oscillations in Lecher's wires to the constants of the circuit.—It was found that in by far the greater number of cases the nodes are not equidistant, but that the space between them increases as the primary condenser is approached, showing that the conditions are not so simple as had been supposed. Above all, the influence of the primary circuit cannot be neglected. The effect of increasing the size of the condenser-plates, and also of diminishing the distance between them, was investigated. The greater the capacity of the primary condenser the more the nodes are shifted towards it, though not all to the same extent, so that a deformation of the system is produced. The form also of the plates, when these are commensurable with the wave-length of the oscillation, has to be taken into account.

When the self-induction of the primary circuit is diminished the nodes are shifted towards the end-condenser, and at the same time brought closer together. In another series of experiments the balls of the primary were separated beyond sparking distance, and wires led from them to a spark-micrometer 5 metres away. With this arrangement the nodes were brought closer to the primary condenser, the nearest being most strongly affected. Their relative intensity was considerably modified, and new nodes not belonging to the same system sometimes made their appearance. When metal tubes 1.045 centimetre in diameter were substituted for the Lecher's wires, the effect of their greater capacity was marked.

On diminishing the capacity of the second, or end-condenser, by separating its plates, a corresponding effect was observed, namely, the nodes appear as it were pushed away from it, and at the same time somewhat crowded together, in consequence of the move-

ment being less in those nearer the primary condenser. The presence of the luminous gas in the vacuum-tubes was found to have no influence on the position of the nodes.

G. J. B.

Disruptive Phenomena in Dielectrics under High Electrical Tension. By C. P. STEINMETZ.

(Elektrotechnische Zeitschrift, 1893, p. 248.)

When a dielectric is subjected to an electrostatic stress of sufficient intensity, its resistance, from being practically infinite, falls suddenly, and a discharge passes. The relation of this critical difference of potential to the material and thickness of the dielectric forms the subject of the present Paper.

The source of electricity was a small 50-volt Westinghouse dynamo, giving 150 alternations per second. The electromotive force was varied for the purposes of the investigation by altering the strength of the exciting current. This dynamo was connected with a step-up transformer, the coils of which could be coupled together so as to give ratios of 1 : 10, 1 : 20, or 1 : 40. For experiments requiring a still higher tension a special transformer was used, with a ratio of 1 : 150 or 1 : 300. The strength of the primary current was measured by an electro-dynamometer. The observations were made as follows:—A plate of the dielectric, of known thickness, was clamped between two metallic electrodes, 5 centimetres in diameter. The primary circuit having been closed, the strength of the exciting-current of the alternator was increased until a discharge took place. This was rendered evident by the sudden fall in the voltage of the primary current, consequent on the short-circuiting of the secondary when the spark passed. The operation was never allowed to last more than a quarter of a minute; but, in spite of this, the material was always more or less heated before the insulation broke down. In the case of liquids and gases, the electrodes were kept apart by small pieces of glass or mica of known thickness. Tables are given showing the thickness of the dielectric, the maximum tension at the time of the discharge, and the electrostatic gradient, or fall of potential, in kilo-volts per centimetre, under which the insulating material broke down. With some substances—e.g., woody fibre (paper), melted paraffin and paraffined paper—the observed P.D. was fairly proportional to the distance between the electrodes; but with others, such as mica, air, &c., the striking distance increased more rapidly than the potential. The Author discusses the applicability of certain empirical formulas to his results, which are summed up in the following Table:—

Material.	Electrostatic Gradient in kilo-volts per centimetre.		
	Tension between the electrodes = 0 kilo-volt.	Tension between the electrodes = 5 kilo-volts.	Tension between the electrodes = 25 kilo-volts.
Air	189·0	16·7	11·9
Mica	4,170·0	3,200·0	1,660·0
Vulcanized fibre (red)	130·0	52·0	15·3
Dry woody fibre	130·0	130·0	130·0
Paraffined paper	339·0	339·0	339·0
Melted paraffin (at 65° C.)	81·0	81·0	81·0
Boiled Linseed oil (at 21° C.)	80·0	80·0	80·0
Turpentine	64·0	64·0	64·0
Copal varnish	30·0	30·0	30·0
Lubricating oil (impure)	16·0	16·0	16·0
Asbestos paper	43·0	43·0	43·0
Superficial discharge.	..	10·1	0·86

The first column, for zero difference of potential, is calculated from the formula adopted by him, the experiments being carried as low as 0·18 kilo-volt, at which point the electrostatic gradient for air was 80 kilo-volts per centimetre. He points out that this formula, which agrees fairly well with the observations, would give a striking distance of 18 centimetres for 100,000 volts and 12 metres for 1,000,000 volts, while the electromotive force of a flash of lightning 1 kilometre long need not exceed 9,000,000 volts—a tension much lower than is generally supposed.

G. J. B.

On the Specific Heat of Different Kinds of Glass.

By A. WINKELMANN.

(Annalen der Physik und Chemie, vol. xlix. 1893, p. 401.)

This investigation was undertaken in order to ascertain with what degree of accuracy the specific heat of a glass can be calculated from its chemical composition, and whether there exists any relation between the specific heat and the thermal conductivity. Eighteen different kinds of glass were examined by the method of Regnault. The values range from 0·2318 for a sample containing 71·8 per cent. B_2O_3 , 22·4 per cent. Al_2O_3 , and 5·8 per cent. Si_2O_2 , to 0·08174 for a compound of 22 per cent. SiO_2 , and 78 per cent. PbO . Normal thermometer glass was 0·1988, and ordinary flint glass 0·1257.

The observed values were compared with those calculated from the specific heat of the constituents, by Woestyn's law, and the Author's results approached more nearly the theoretical values

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than those of Kopp. A special determination was made of the specific heat of Boric acid, which was sealed up in glass tubes to prevent the possible absorption of moisture. The mean value obtained was 0.2365. The Author considers that the specific heat of glass can be calculated by Woestyn's law within 1 per cent., the greatest observed error being 2 per cent. in a case where there was some uncertainty in the proportion of one of the constituents; but he was unable to find any simple relation between specific heat and thermal conductivity.

G. J. B.

On the Diathermancy of Certain Glasses of Known Composition.

By R. ZSIGMONDY.

(Annalen der Physik und Chemie, 1893, vol. xlix., p. 535.)

The behaviour with regard to radiant heat of alumina and ferrous oxide, when dissolved in the substance of a glass, is exactly analogous to that of aqueous solutions of these compounds. While the presence of an abnormal proportion of alumina has little influence on the diathermancy of a glass, a very small percentage of ferrous oxide produces a marked increase in its power of absorbing heat-rays. The Author gives details of experiments with eight samples of glass of various kinds, free from iron. These, in plates from 7.5 to 8 millimetres thick (0.3 to 0.32 inch), transmitted from 58.4 to 63.14 per cent. of the heat from an Argand burner. On the other hand, a soda-alumina glass with 8 per cent. of alumina, coloured pale bluish green by a slight trace of iron, allowed only 20.97 per cent. of the radiant heat to pass. Another specimen of lime-soda crown glass, containing about 1 per cent. of ferrous oxide, transmitted 0.72 per cent. This sample was blue green in colour. A plate of green glass with about 2 per cent. of iron stopped the heat rays entirely. The Author believes that this discovery may be utilized in providing transparent screens to arrest radiant heat.

He also suggests the possibility of determining from the diathermancy of any given glass whether the iron it contains is in the ferrous or the ferric condition, the presence of a small quantity of this substance having a much greater effect than a considerable variation in any of the other constituents.

G. J. B.

On the Diathermancy of Aqueous Solutions of Ferrous Salts.

By R. ZSIGMONDY.

(Annalen der Physik und Chemie, 1893, vol. xlix., p. 530.)

Alum, whether in crystal or in solution, is credited with a special power of stopping the ultra-red rays of the spectrum, in spite of the fact shown by Melloni, that in the solid state it absorbs a smaller percentage of the invisible heat-rays than ice, and that in aqueous solution it is less effective in this respect than water. Franz, in 1855 and 1857, called attention to the thermal properties of coloured salts of iron and copper, and the Author has now studied the action of colourless solutions of ferrous compounds. The source of heat used was an Argand burner, the measurements were made with a bolometer, and the liquids were contained in tanks with glass sides 9.5 millimetres ($\frac{3}{8}$ -inch apart).

The power of the solution to absorb heat appears to depend upon the percentage of the metal present in the ferrous state, ferric salts having comparatively little power. The influence of the acid is in general not marked. A solution of ferrous chloride, containing 2.8 per cent. of the metal transmitted 4.06 per cent. of the total heat; a similar solution of ferrous sulphate had an equal effect. Ammonio-sulphate of iron allowed 4.4 per cent. to pass, but ferric chloride of the same strength transmitting 11.2 per cent. of the heat-rays, i.e., only 1 per cent. less than pure water under like circumstances. Using a larger tank, a layer of liquid containing 0.35 per cent. of iron as proto-salt with a depth of 54.3 millimetres ($2\frac{1}{4}$ inches) was found to arrest all but 3.29 per cent. of the heat-rays, and to appear practically colourless by daylight.

G. J. B.

I N D E X

TO THE

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Fig: 19.

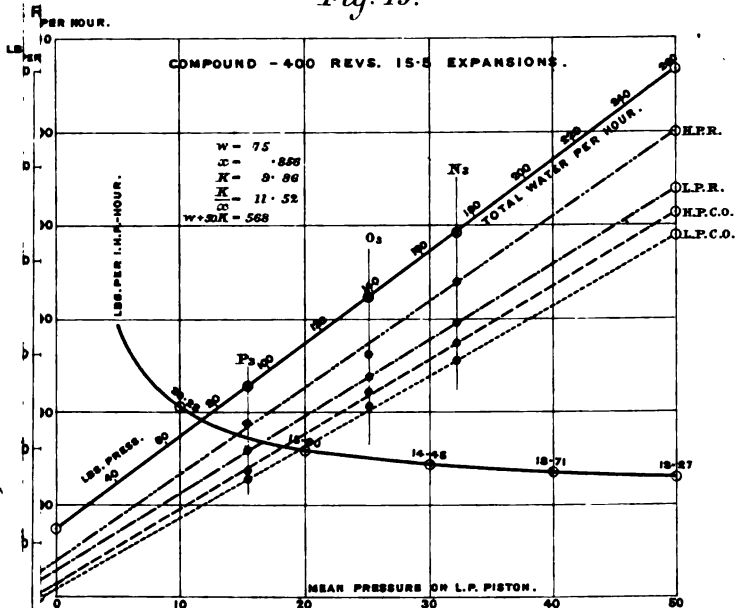


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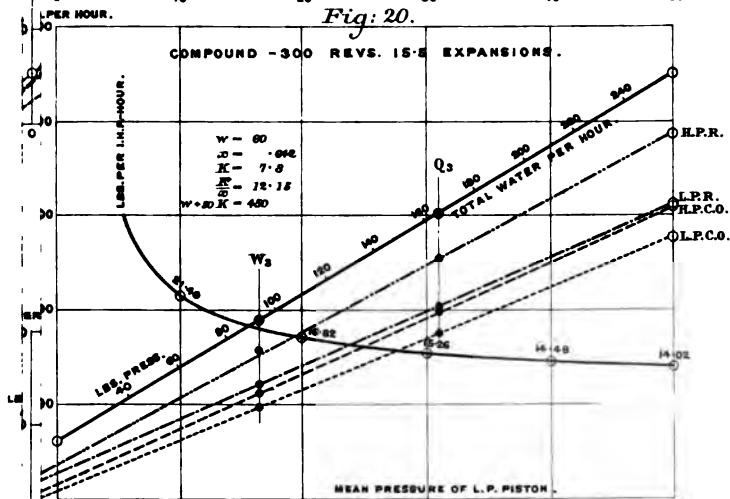
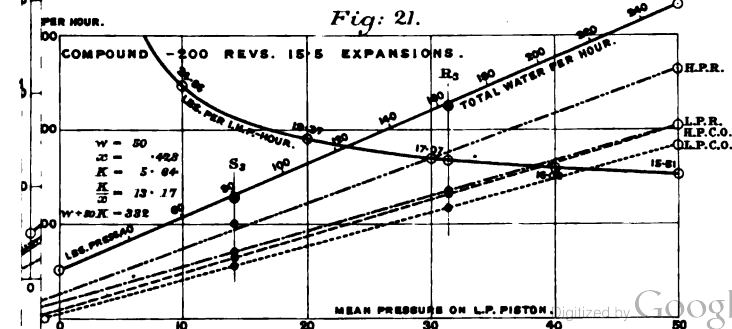
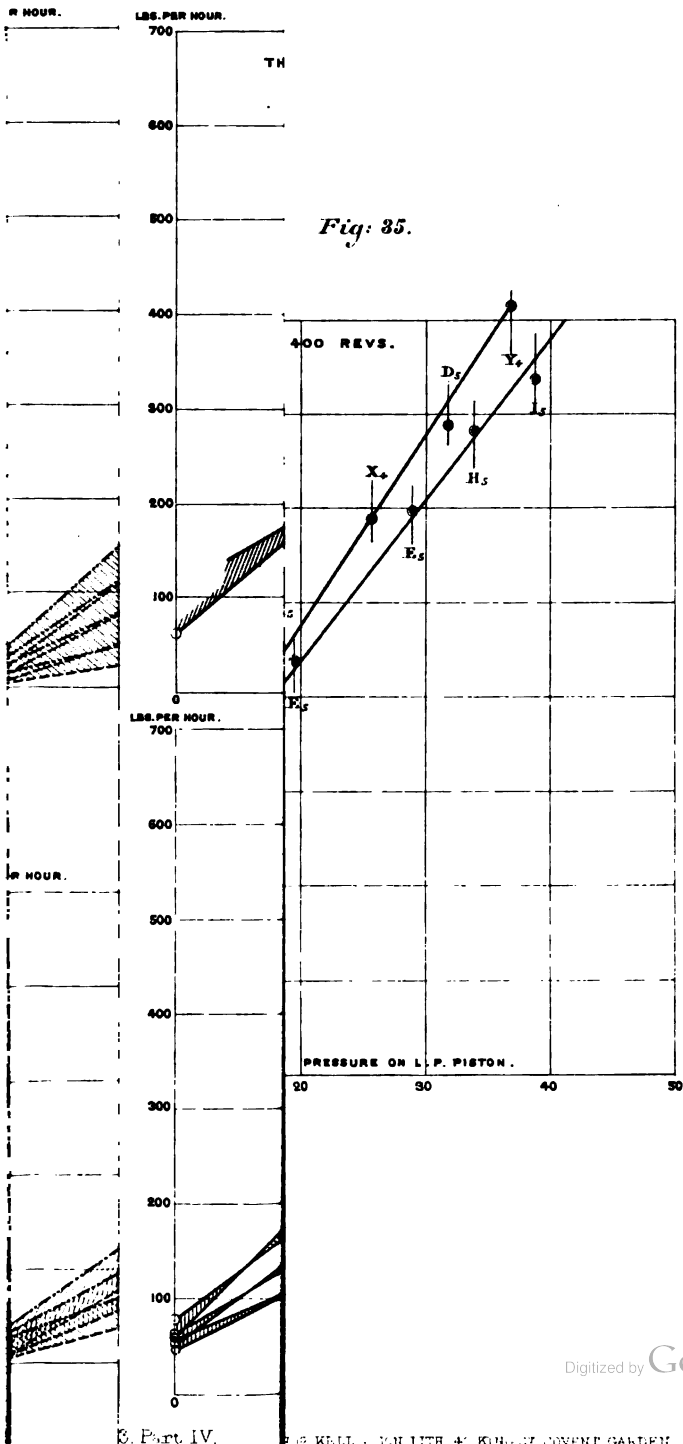
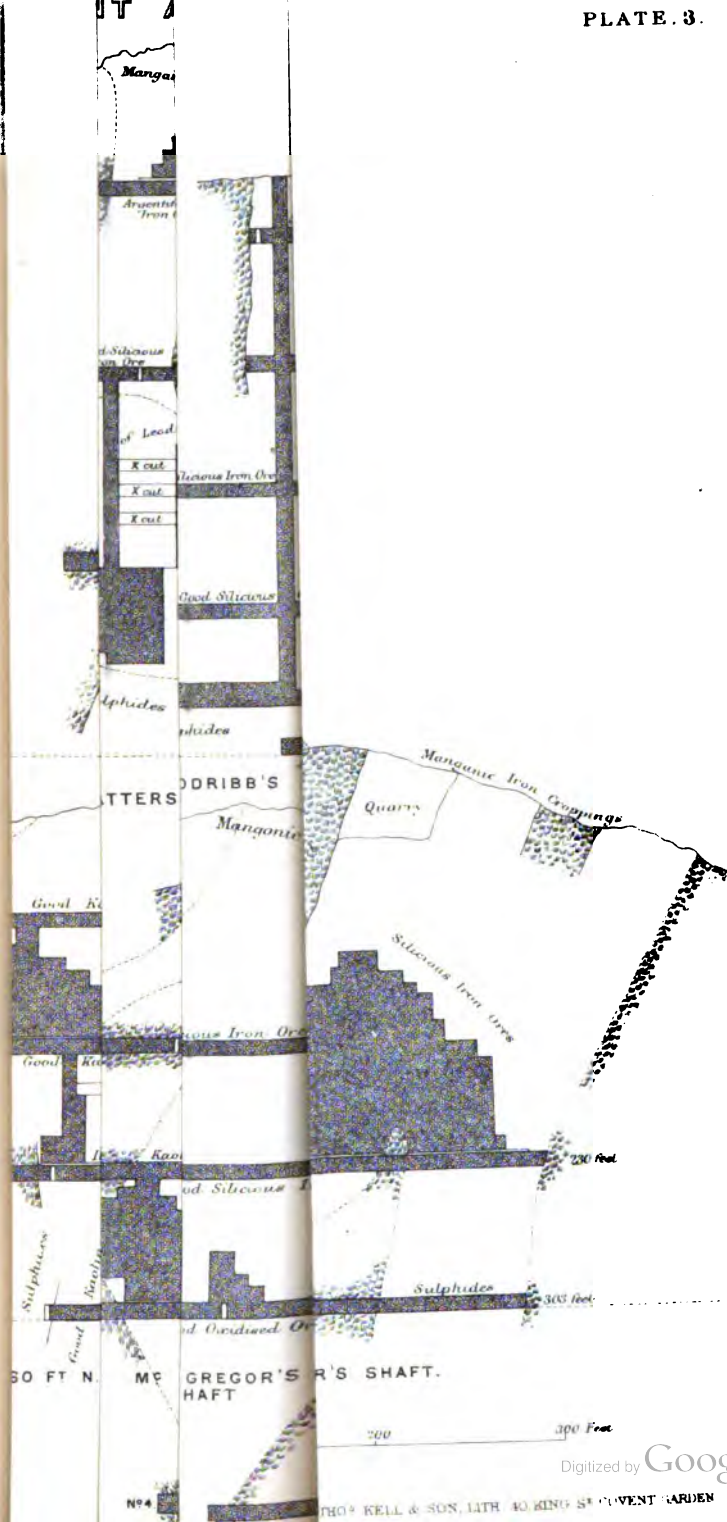


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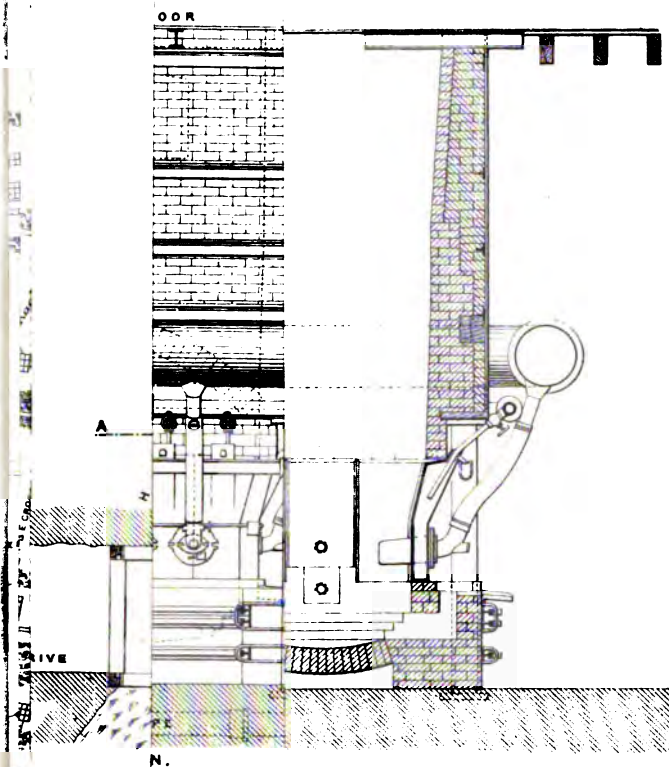
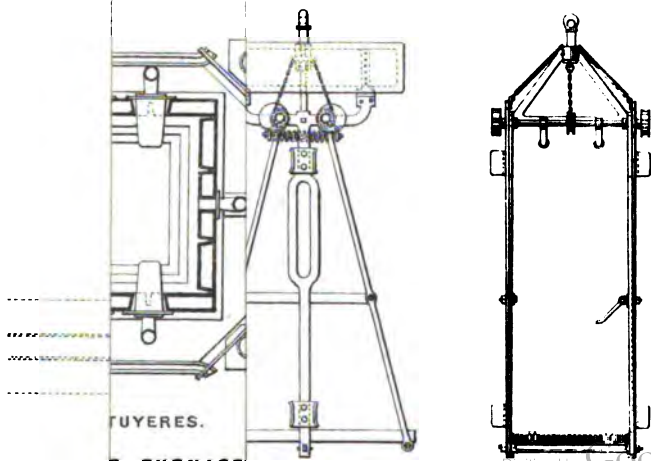
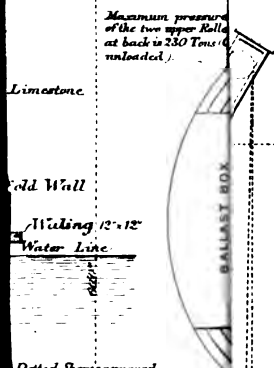


Fig 7.



SYSTEM

SAFETY-CAGE.



Dotted Shows removed and short ones fixed against face of work as it was brought up

P.C. Concrete

Rock Bottom

revised into wall and to hold dam

12"x12"

12"

400'

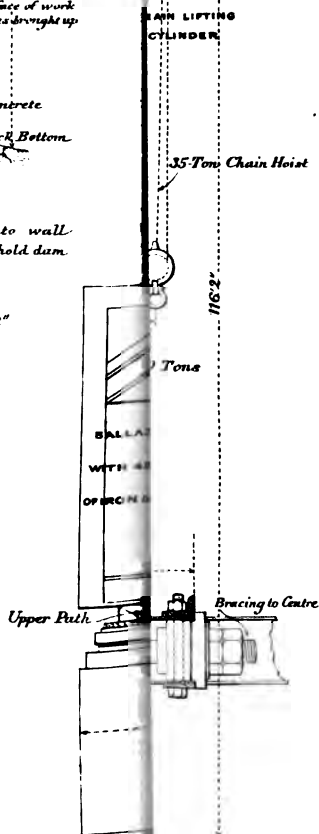


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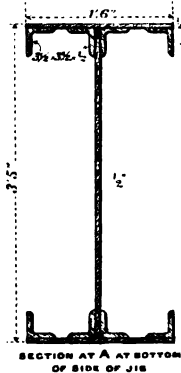


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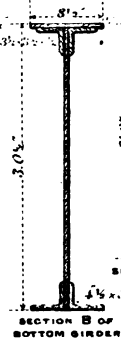


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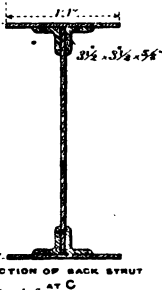
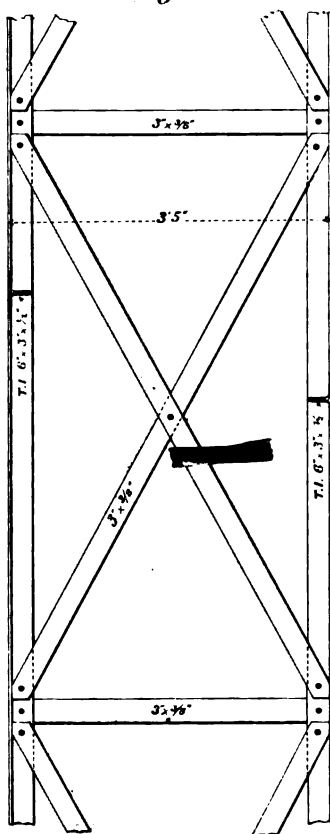


Fig. 9.



Scale: 20' Feet = 1 Inch

tes of Proceedings

Fig. 1.

Enter 21

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7

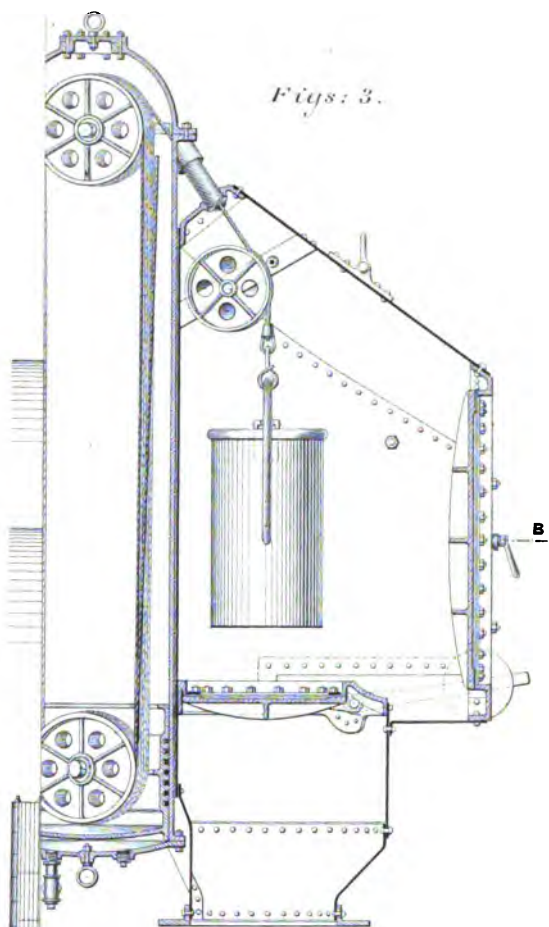
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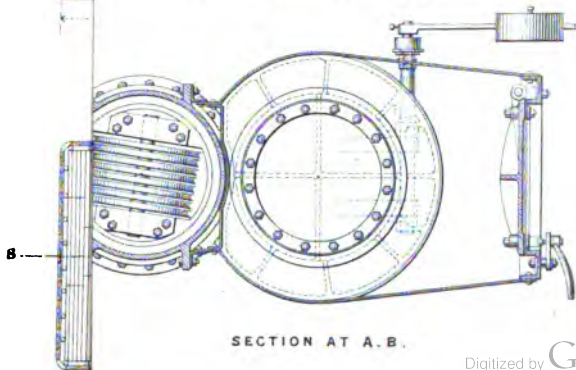
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W

6

Sod



CLAY HOIST.
SECTION THROUGH CENTRE.



SECTION AT A.B.

1 2 3 4 5 6 7 8 9 10 11 12 Feet